SIMULATION STUDY

BITUMINOUS CONCRETE PLANTS

R. M. LEWIS
J. W. WILKINSON
N. F. BOLYEA

RENSSELAER POLYTECHNIC INSTITUTE

A SIMULATION STUDY OF

BITUMINOUS CONCRETE PLANTS

by

Dr. Russell M. Lewis

Dr. John W. Wilkinson

and Norman F. Bolyea

Conducted for the
New York State Department of Transportation
Engineering Research and Development Bureau
in cooperation with the
United States Department of Transportation
Federal Highway Administration
Bureau of Public Roads

RENSSELAER POLYTECHNIC INSTITUTE

Troy, New York

1969

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

NYSDOT
Library
50 Wolf Road, POD 34
Albany, New York 12232

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The bituminous concrete plant was studied and various methods of modeling the plant were reviewed and evaluated. The Monte Carlo simulation technique was selected and applied. A digital computer program was developed which models the aggregate gradation produced by the plant.

The simulation first randomly selects the operating characteristics of a typical plant. The aggregate production is then randomly generated for the output of each of the several hot bins. The true gradation for each batch is recorded together with the apparent gradation of periodic batches as obtained from the sieving of small samples. The apparent gradation contains errors due to sampling, splitting and sieving.

The model can be used to apply different testing procedures and specifications and study their effect. Thus, the desirability of various quality assurance procedures can be evaluated and an optimum testing strategy developed. The techniques employed and many of the building blocks developed are applicable to other bulk material processes such as the portland cement concrete plant.

The simulation described is a conceptual model based upon limited field data in New York. The State of New York has additional work in progress that may be used to further refine and calibrate the model. The program, coded in the FORTRAN language, is described in detail.

INTRODUCTION

BACKGROUND

General

Bituminous concrete plants are used to produce material for highway pavements and many other surfaces such as shoulders, driveways, parking lots, airfields, aprons, dams and irrigation canals. In the highway field bituminous concrete is one of two competing materials for high-type pavements and various asphalt mixes are used almost universally for the construction of intermediate and lower type roads and for the resurfacing, maintenance and patching of all types of paved roads and streets.

Bituminous concrete plants are spotted throughout the countryside, often located adjacent to a quarry or gravel bank as a source of aggregate. As transportation is a significant factor of the total cost of these materials, a large number of plants have been built to supply local needs at a reasonable travel distance.

The major components for these plants are manufactured by several firms, but the manner in which they are assembled and installed vary widely. Various parts of the plants are constructed locally and adapted to the unique characteristics of the site and the requirements of a particular operation. Thus, even though all plants are basically similar, a wide variation exists between the capacities and their physical and operational characteristics.

The plants may be privately owned or may be owned by a local governmental unit. In New York State some 120 plants are producing material used in State work. The State has a strong interest in controlling the operation of these plants to assure that a good product is produced.

The final objective in the control of a bituminous concrete plant is to obtain the best pavement that is consistent with economic constraints and that will meet the environmental and traffic loads to which it will be subjected. A good product is one that can be produced efficiently and economically and will perform well during a long, useful life. In addition, a good product should be uniform and consistent to permit periodic tests to be meaningful and to minimize adjustments in plant operation and in the placement and compaction of the material.

The adequacy of the material in place is dependent upon several factors. The material properties are a function of the physical and chemical properties of the aggregate and bitumin and the surface characteristics of the aggregate. Plant operation variables effect the dryness of the aggregate, the gradation of the aggregate blend and the proportioning of the aggregate and bitumin. The properties of the mix are also dependent upon mixing time and temperature. The final product is further altered by handling and construction practices (19)*.

*Numbers in parentheses refer to entries in the List of References

Description of the Plant

In order to understand the problems associated with modeling the plant, it is advisable at this point to briefly describe its makeup and operation (17). The components of a typical asphalt plant are illustrated in Figure 1. The type of plant shown is the batch mix plant which is presently the more common type in use. The other type is called a continuous plant, in which the weigh hopper is replaced by feed mechanisms which proportion the aggregate. The aggregate mix is then fed continuously into a pugmill where the asphalt is injected and in which the mixing takes place. In this study, the batch type plant was used to illustrate the process, but the model developed is applicable to both types of plants.

The production process for the batch mix plant may be described as follows:

(1) The aggregate is transported from separate stockpiles by truck or bucket loader and is placed into individual cold bins. As the material in the stockpiles is sorted by size, the aggregate in the cold bins is similarily sorted.

(2) The aggregate is volumetrically dispensed from each cold bin onto a common feed belt. At this point, the aggregate sizes become intermixed.

(3) The cold aggregate blend is then fed into a dryer.

(4) The dried aggregate blend is transported to the gradation control unit at the top of the plant tower.

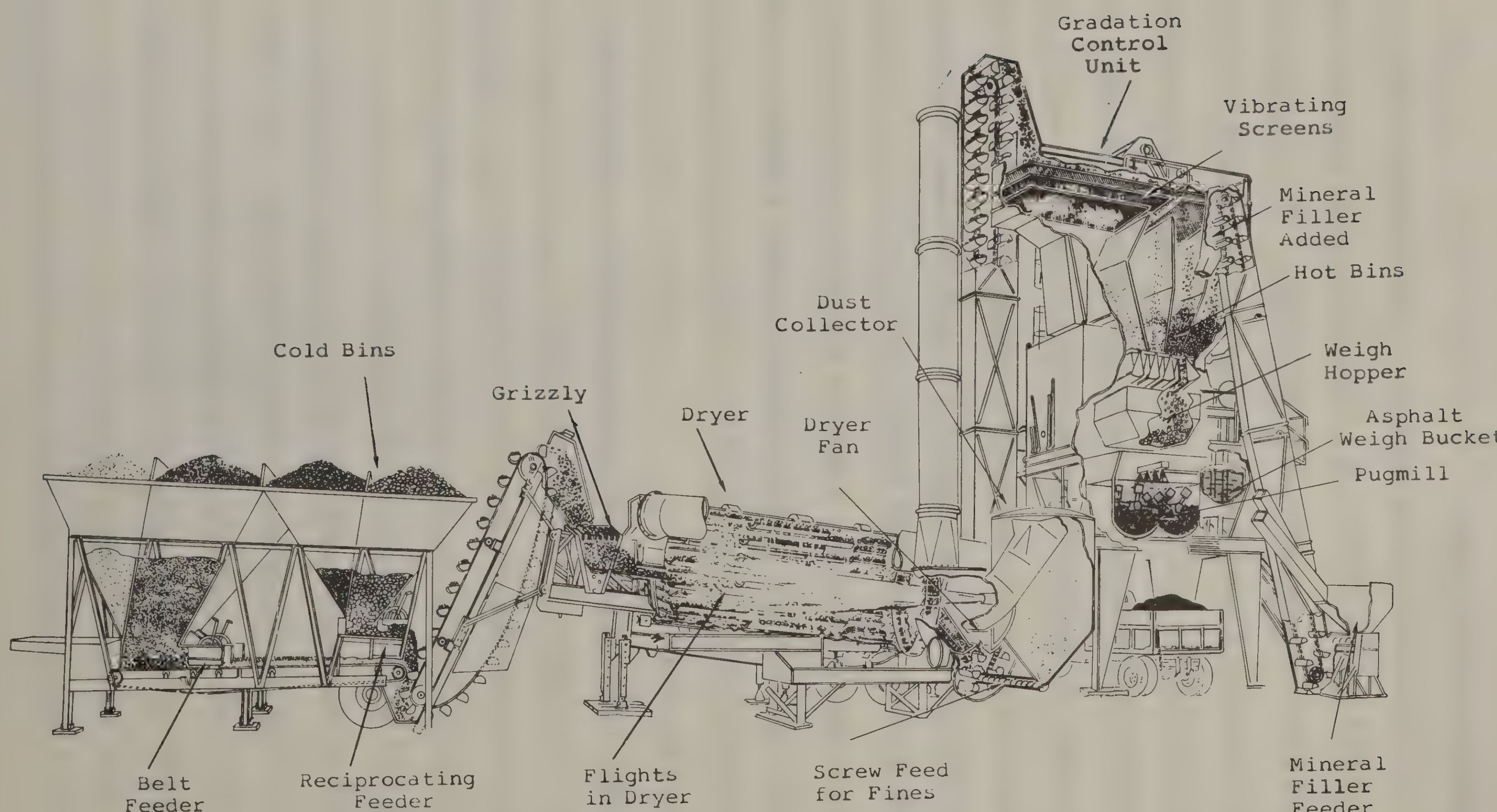


FIGURE 1. DIAGRAM OF AN ASPHALT BATCH MIX PLANT

(5) Vibrating screens separate the aggregate into size ranges.

(6) The heated and sorted aggregate is held in the hot bins. Plants generally use three and sometimes four hot bins.

(7) The aggregate blend is proportioned by withdrawing the various size ranges from the hot bins. Sampling apertures are located below each hot bin. The material from each bin may be sampled by holding a sample tray or a shovel in the stream as the aggregate drops from each of the bins.

(8) The aggregate drops into the weigh hopper where it is proportioned by weight to conform to the prescribed plant mix ratio.

(9) The blended aggregate then drops into the pugmill where asphalt is added and the material is thoroughly mixed.

(10) The mix is finally dropped into a truck for transportation to the job site.

Drying of the aggregate is required to properly coat the aggregate with bitumin, thereby obtaining the desired physical properties of the asphalt mix. Secondly, the dried aggregate can be more precisely sorted. If screening of the cold or wet aggregate were to be attempted, many of the smaller particles would adhere to the large particles and be carried over to the larger sized bins. Moreover, the wet material

would tend to clog the openings in the smaller-sized screens.

It may be seen that the function of the feeds from the cold bins is to closely approximate the desired aggregate blend to assure that the proper ratio of sizes is fed to the tower. If an insufficient quantity of one size is fed through the dryer, one of the hot bins may become empty. Conversely, if too much of one size is supplied to the gradation control unit, one of the screens may become overloaded, which results in finer material being carried over into a coarser bin. In either event, the end result disrupts the planned aggregate gradation (9).

Gradation Control

Various user groups have established limits within which the distribution of aggregate particle sizes must lie. These limits are based in part on the theoretical basis of providing a dense well graded blend in which the smaller sizes nest between the voids left by the larger sizes. The limits are also based on experience gained by correlating the size distributions used and the resulting performance of the pavements.

Table 1 lists the New York State sieve series used in determining all gradations. Figure 2 illustrates the gradation specification currently used by the New York State Department of Transportation for top coarse mixes, type 1A (12). It shows the band within which the distribution of particle sizes must lie. In using this specification, a contractor selects a job mix formula (JMF) which passes through this band.

TABLE 1

NEW YORK STATE STANDARD SIEVE SERIES

Sieve Size	Square Opening in inches
1/2 inch	0.5000
1/4 inch	0.2500
1/8 inch	0.1250
No. 20 mesh	0.0331
No. 40 mesh	0.0165
No. 80 mesh	0.0070
No. 200 mesh	0.0029
Pan	0.0000

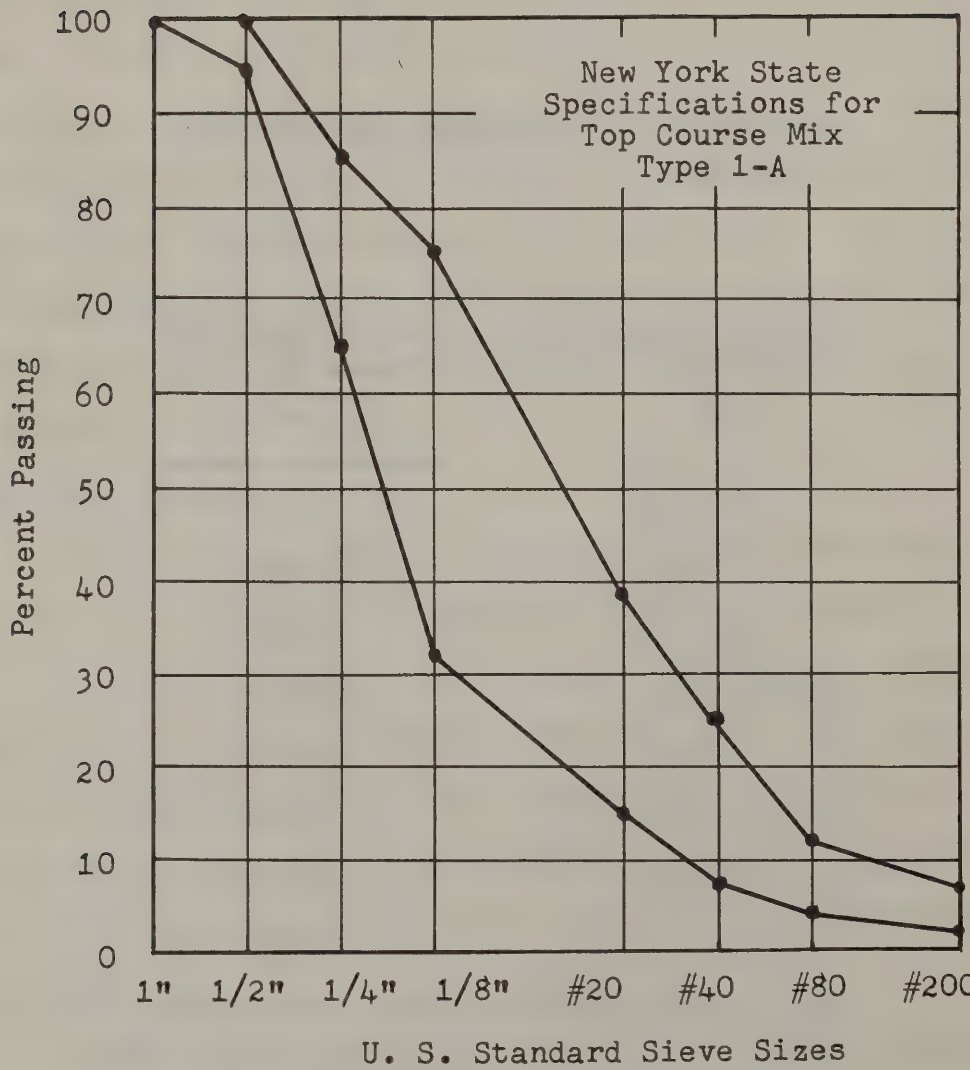


FIGURE 2. BITUMINOUS CONCRETE GRADATION SPECIFICATION

The formula chosen is a function of the particular aggregate used and the characteristics of the plant. Having selected this job mix formula, he is then held to producing an aggregate blend that does not vary from it more than a prescribed amount. These tolerances were selected to exclude the blend, if the percent of material retained on any sieve varied more than two standard deviations as determined by a comprehensive field survey and study previously conducted by the State (5).

The contractor establishes a plant mix ratio (PMR), which is the percentage of aggregate that is to be taken from each hot bin to form the final mix. It is based on the expected gradation in each bin and the desired job mix formula. Modern equipment, especially for those plants with automatic controls, permits close adherence to the specified plant mix ratio. Errors are likely, however, due to the material in the hot bins varying from the desired distribution of sizes and due to the segregation of sizes within the bin itself.

The actual distribution of sizes in the resultant mix can be estimated by taking a sample of the final mix. The bitumin must be removed through an extraction process before the aggregate is graded. The aggregate is then passed through a series of sieves and the percent passing or retained on each sieve is measured by weighing. An extraction of the bitumin requires an hour and a sieve analysis can be done in about 15 minutes. Batches, on the other hand, are produced at a rate of about one per minute.

The standard testing procedure for an asphalt plant is to sample at each hot bin as the material is dropped into the weigh hopper. These samples, one for each hot bin, are then sieved to find their gradations. The results are then combined mathematically using the plant mix ratio to estimate the overall gradation of the mix. This is called a complete hot bin analysis and requires about 45 minutes. Even if this procedure were done for each batch, by the time the test was performed and analyzed, the batch would most likely be in place on the road surface. Because typically such complete sieving tests are only performed about once an hour, this procedure merely provides historic data.

In an attempt to reduce the testing effort required, New York State has instituted a simpler test known as the hot bin uniformity test (13). The sampling procedure is that already described, but the sieving procedure is simplified. Each hot bin has primary size, defined as that size range in which most of the particles fall. For example, for the number 1 bin the primary size may be material that has passed the 1/2 inch sieve and retained on the 1/4 inch sieve, whereas the number 2 bin has material between 1/4 and 1/8 inches as the primary size. The uniformity test determines only the percent of the primary-sized material for each bin. While the test is somewhat simplified in that fewer sieves must be weighed and fewer computations are required, the time required is still on the order of 20 minutes.

PURPOSE AND SCOPE

Research Objectives

The long term objective of this research is to improve the quality assurance of asphaltic concrete. The work is limited at this stage to providing a desired blend of aggregate sizes. It should be noted that this alone does not necessarily assure a good pavement. The problem of optimal mix design is a most important but clearly separate problem. We are concerned here only that, given a specified aggregate blend, how can we best assure that it is produced within acceptable limits.

The specific objective of this individual project was to show the feasibility of modeling an asphalt plant and to demonstrate the applicability of the simulation method. It was not considered possible in this first project to produce a highly sophisticated and completely validated model. It was felt, however, that a preliminary model would show the usefulness of the simulation method and demonstrate the application of the model to problems such as the relationship between testing strategy and process control.

As more comprehensive field data are collected and analyzed, the model can be further refined and calibrated. Such a model then could be extensively run under controlled laboratory conditions to test many control techniques and to develop an optimum control strategy.

Scope of the Study

The purpose of the project was limited to the study of the aggregate blending process in the bituminous concrete plant. Specifically, the research tasks included:

1. A review of the state-of-the-art.
2. An analysis of existing data.
3. The design of a conceptual model.
4. The development of a computer program for the model.
5. Showing the applicability of the model to achieving the research objectives stated above.

SOURCES OF DATA

The New York State Engineering Research and Development Bureau has conducted extensive field surveys of bituminous concrete plants. Analysis of these data gives some insight into the process that occurs in the plant and is necessary in order to model the operation. Observations must also be used to select parameters and calibrate the model that is developed.

1961-1964 Survey

During the period 1961 through 1964, 55 plants producing top course mix were visited at which 868 hot bin and 682 mix samples were obtained (5). Of these plants, 51 were batch type and 4 were continuous plants. At this time automatic control was just beginning to be instituted and at 16

plants batching was performed manually, 32 were semiautomatic and 7 were automatic, including the 4 continuous plants. Batches were sampled about once each hour.

The initiation of this testing program focused attention on the problems and apparently resulted in decided improvements, as the variations were markedly reduced after the first year. Therefore, the 1961 data were omitted from further analysis. Other data were then omitted for various reasons, such as the number of observations being too small to be significant.

The remaining data that were analyzed for this project then consisted of 341 samples from 20 plants collected during the period 1962 through 1964. Each of these samples yielded the gradation for each hot bin as sampled when it dropped into the weigh hopper. The percent retained on each sieve was measured and the means and standard deviations were computed.

As these samples were taken at intervals of approximately an hour, the results give no information on the short-term variations for which the plant can be assumed to be operating steady-state with a relatively constant input and under stable conditions. Furthermore, only the output was observed, and no information was gained about the internal occurrences within the plant.

1967 Survey

As part of this project, technical assistance was given to the State in setting up a pilot study that was conducted during the summer of 1967. This was a field survey in which

intensive sampling was performed specifically to gather the type of information needed to model the plant process.

Samples were taken at the beginning and then the end of the process separated in time by about 10 minutes. As this is the time required for aggregate to move through the plant, the assumption can be made that the same material is observed at both ends.

Pairs of samples were also taken at each end as close in time as physically possible. Thus, the populations from which the pair of samples were extracted can be treated as constant; and the differences observed between the pair of samples is indicative of the errors inherent in extracting a small sample from a large flow.

The sampling procedure was as follows:

1. Three samples were taken at the cold feeds, one for each bin.
2. Immediately afterwards, a corresponding set of three samples were taken at the cold feeds.
3. Ten minutes later, three samples were taken at the hot feeds.
4. Immediately afterwards, a corresponding set of three samples were taken at the hot feeds.

An entire set then consists of 12 samples. This work was performed at the continuous plant at Middeville, New York. Thirty sets of 12 samples each were obtained.

<u>1968 Survey</u>

Based on the experience gained during the 1967 survey

a large scale testing program was established for 1968. Detailed field observations were made at 46 bituminous concrete plants around New York State. For 39 of these plants, sampling was performed on a comprehensive basis. Four plants were intensively sampled using the same procedure employed for the 1967 study. The processing of the resulting 15,000 samples (drying of cold samples, splitting and sieving) has been a major undertaking requiring 1 1/2 years.

This study represents the first extensive time series data ever acquired for a bituminous concrete plant. The analysis of the results will provide the information needed to calibrate and refine a simulation model. This analysis was not available, however, for this present project. The model was based on the 1962-1964 and the 1967 surveys. Nevertheless, the model was constructed to facilitate refinement when the results of this extensive 1968 survey are completed.

DEVELOPMENT OF A MODEL

THE CONCEPT OF MODELING

A model is an approximation to reality. Usually the closer it emulates reality the more complex it becomes. Such complexity makes it more difficult to use as an aid in interpreting or understanding the process it models. Hence, there is always a trade off between simplicity and validity, with the criteria being to make the model as simple as possible and still perform the task required (2,8).

Physical Models

There are several modeling techniques which might be applied to this problem. The first is the physical model which is a direct representation of the process. A full-scale model would be the asphalt plant itself. One could be used specifically for research purposes. To provide better control of the aggregate flow process the material could be recirculated; thereby providing uniformity of input and a steady-state situation. Some degradation and deterioration of the aggregate would occur under these conditions in which particles would be broken down into smaller sizes and very small particles would be lost as dust.

The Barber-Greene Company conducted such full-scale tests to study the operational characteristics of its dryer (1). Such an approach, however, is costly and it is difficult to control the many operational and environmental factors

which affect the process.

The overriding difficulty with this approach is that one is faced with a process that is most difficult to observe, in which the sampling must be done sporadically in very small quantities and for which the testing procedure is tedious and time-consuming.

An alternative approach is the small-scale physical model, which may be brought into the laboratory where many conditions may be more precisely controlled. In the asphalt plant, however, we are dealing with an aggregate flow in which the particles already range down to extremely fine sizes. Miniaturization offers no real advantage and would be extremely costly.

Analogous Models

A second method would be to develop an analogous model. Stephens investigated the problem of aggregate segregation within a bin by utilizing colored ball bearings of a uniform size (16). While such an experiment might give some insight into the real problem, the obvious shortcoming is representing the full range of sizes found in an aggregate flow. The provision of balls of varying size puts us right back into a full sized physical model.

A different approach would be to model the aggregate flow by representing the individual particles by numbers in an array in a digital computer. Such a procedure has been employed successfully for the simulation of vehicular traffic flow. In simple form, a vehicle has been represented by a

"1" and a space by a "0" in a binary word (4). A more sophisticated procedure used an entire computer word to represent a vehicle by coding its location and characteristics into the word (7).

Such a digitized analogous model was investigated for this project. It is a brute force technique in which individual particles or particle groups are processed by the computer. Individual components such as the screens and the bins are represented by building blocks through which the aggregate flow is moved. For example, Figure 3 is an array which simulates the flow in a bin. The flow is treated two dimensionally by considering only one plane through the bin. Although the concept could readily be extended to three dimensions, the magnitude of the problem would be tremendously expanded.

In Figure 3, seven different particle sizes are represented by the digits "1" thru "7". The program removes digits from the bottom and then scans the bin, row by row, from the bottom up. Digits are allowed to drop down into voids created in the row below. Then new digits are entered from the screens above. Rules based on probability theory are used to determine how individual digits flow thru the bin. For example, a digit may drop directly downwards or on either diagonal. A digit near the center of the flow may have a higher probability of dropping than one near the wall (shown by "X's").

```
Screen    X X X X X X X X X X X X X X X X X
                 6       7 1       4

          X                                X
          X4                               X
          X73                              X
          X51 475 4 1                    37X
          X472 366 1275              326742X
          X531712 4 371 47231572 471 5114 X
          X74625413614647 14672537 1243674X
          X 46731746213674125375276 22 3567X
Bin       X35762537471461536 72 3524741365 2X
Array     X351576 452637141146276 33 456273X
          X463721363 14562336726333572771 2X
          X4532264175151462746 3 4536112437X
          X4563672736462711463755637 2 3542X
           X45637564667473625311512571467X
            X17146325673 1462733527354 71X
             X3355271564357 26 356456214X
              X567354213151764534723  X
               X41567363541564524675 X
                X14116756226 4635753X
                 X4756773562534541 6X
                  X354621476354543X
Column             X4157647735 45X
                    X4531546632 1X
                     X 37465246X
                      X4115732X
                       X3  57X
          Row           X   X
                        X   X
                            7
                          516
                          4
```

FIGURE 3. AGGREGATE FLOW IN A BIN

REPRESENTED BY A COMPUTER ARRAY

This procedure is a direct analogy for flows in which all the particles are the same size. It must be modified to account for the aggregate problem. Basically each digit must represent a unit volume of a particular size. The rules for processing the flow then give the opportunity for the smaller particles to sift through the larger ones. It should be noted, however, that some 125,000 particles passing the 200 sieve could fit into the same box as one 1/4" particle. The limitations and inefficiencies of this model are readily apparent.

Functional Models

A functional model describes the basic interrelationships among the variables and parameters. In essence, the process is reduced to a mathematical equation. To accomplish this, much knowledge is needed about the entire process. As previously mentioned, little is known about the internal flow within the asphalt plant and the number of variables is very large. This procedure was considered to be beyond the capability of the state-of-the-art.

Prediction Models

A more relaxed form of the functional model is sometimes referred to as a prediction model - one that permits inferences to be made without complete knowledge of the inner workings of the system. For management purposes such models often suffice (3).

One approach is to develop a prediction equation through the use of regression analysis. The output of the plant would

be observed as well as the input and various plant process and environmental factors. Factors to be recorded would include: dryer type, size, angle charging rate, burner nozzle and air input; screen area, wear, speed and loading rate; feed mechanisms, type and settings; aggregate moisture content, type, shape and gradation; plant mix ratio, number of batches since plant mix ratio was changed and number of batches since beginning of day; temperature, humidity and time of day. Through regression techniques the output would then be correlated with the significant variables and a prediction equation established (20).

For the asphalt plant the situation is considerably complicated by the fact that the output cannot be described by a single dependent variable. The raw data consists of percent of material retained on each of eight sieves for three or possibly four bins. These may be combined by using the plant mix ratio to calculate the percent retained as if the sample were taken from the pug mill. We still have eight dependent variables which are in themselves interdependent in that they must all total 100 percent. That is, if one percent retained increases, one or more of the remaining ones must show a corresponding decrease.

One solution to the problem of multiple output variables is to convert them to a single index to use as the dependent variable. One index that is often used is the sum of the squares of the deviations. For each sieve, the deviation between the observed percent retained and the job mix formula

is determined and then squared. Figure 4 illustrates these deviations. The sum of these quantities for all sieves is the single index of how well the output compared with the desired gradation. The smaller the index the better the fit.

The problem with this index is that deviations for some sizes may be more critical than deviations for other sizes. Furthermore, negative deviations may be more critical than positive deviations. A system of weighted deviations could accommodate these criteria. Further work would be needed to establish these weights.

The major problem with the single index approach, in addition to it being a significant change from standard practice, is that it averages deviations over the range of sieve sizes. The accepted procedure is the more comprehensive requirement that specifies that gradations must fall within an envelope. Quality assurance specifications frequently set different tolerances for each percent retained. However, for the purposes of comparison the somewhat crude single index for the goodness of a gradation curve has considerable appeal and offers definite advantages.

The development of separate prediction models for each of the output variables as functions of various plant and environmental factors would also be a possibility. If appropriate data were available, regression techniques should be helpful in the construction and evaluation of such models. Such data are not available currently and might be most difficult to obtain at any time because of the difficulty (i)

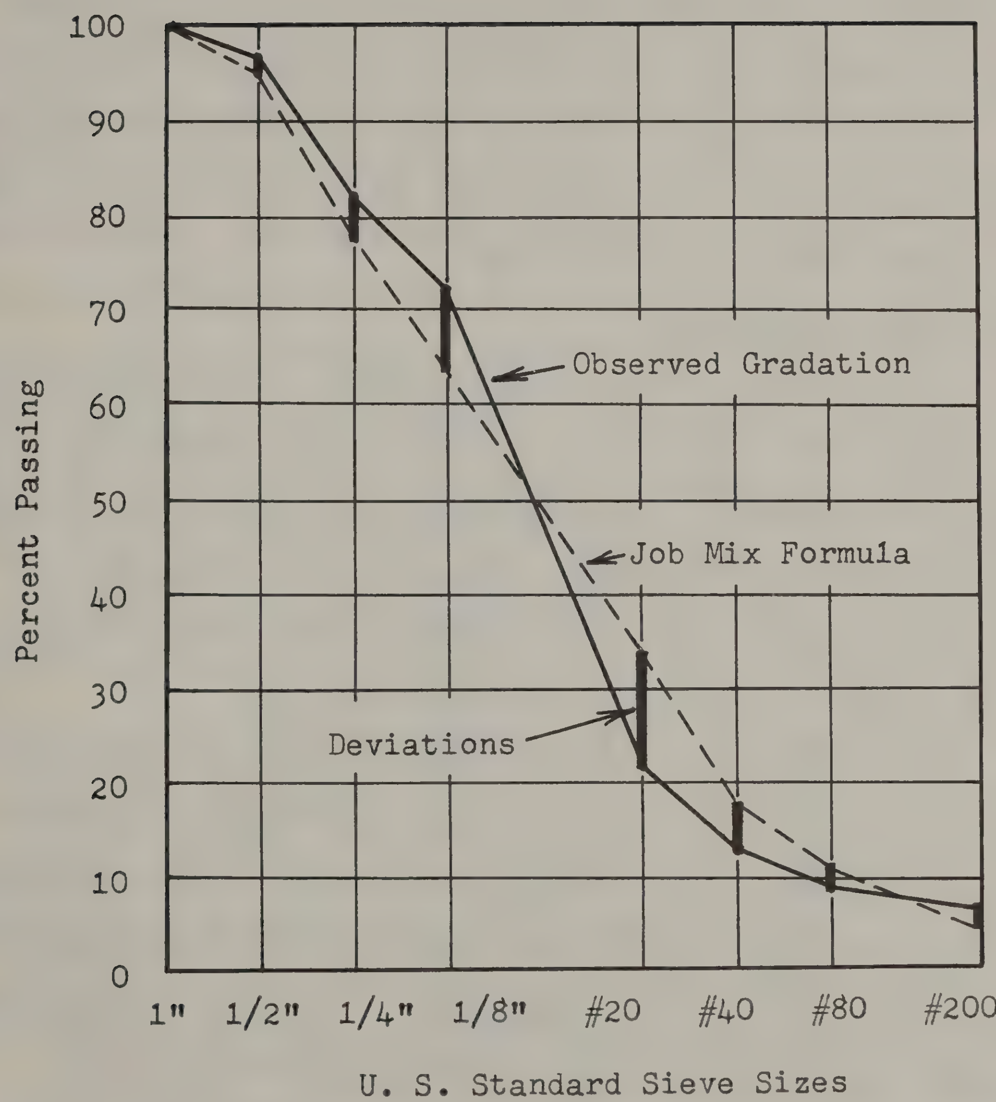


FIGURE 4. COMPARISON BETWEEN THE SPECIFIED AND OBSERVED GRADATIONS

to measure some factors, (ii) to quantify certain influential factors, (iii) to vary certain factors over a reasonable range in a production facility, and (iv) to observe variability in the aggregate characteristics and the environmental factors over a short sampling period. The problems mentioned could be resolved and an appropriate sampling plan designed, but the operational problems of carrying out such a plan would be quite large.

Monte Carlo Simulation

The modeling of the asphalt plant is inherently a probability problem. The flow, mixing, drying, screening, segregation, and feeding of the aggregate will cause the gradation to vary from batch to batch. Moreover, the sampling and testing procedures introduce random errors. These variations may be handled as a probability problem (21).

The modeling, however, cannot be handled rigorously and analytically by existing probability theory. Insufficient information about the process exists. Such factors as the interdependence of the dependent variables and drift, which may or may not be accompanied by changes in control, preclude the direct mathematical approach.

Monte Carlo techniques use a series of random numbers from analytical or impirical distributions to provide the random nature of the aggregate flow and the testing. A series of rules are followed to generate the aggregate distribution. A testing strategy may be specified and the test results displayed. The amount of computation is so voluminous, however,

that this method would have been unthinkable prior to the advent of the high-speed electronic computer.

A special advantage of this technique is that all variables may be precisely controlled and the entire production can be observed and analyzed. This work can be performed very rapidly in the computer, whereas comparable field observations would take years. In the case of the asphalt plant, the aggregate gradation is generated by the computer for each batch and its true gradation is continuously known. One can also measure the gradation through a sampling and testing procedure which contains inherent errors. Thus, the test results for selected batches are readily compared with the generated "true" gradations for all batches.

A second important advantage over "real world" methods is the ability to reset the random number series for additional runs in which different testing strategies are tried. By repeating the series the same identical aggregate flow is repeated. Therefore, the differences in results are independent of any differences in the observed flow. Of course, data from the real world are needed to validate models developed for the suggested computer experimentation.

FORMULATION OF THE MODEL

Investigation of the problem of model formulation lead rapidly to the fact that very little was known about the internal workings of some of the components of the asphalt plant

and about the interactions between these component parts. Little data have been collected at the cold end of the process because of the necessity to oven dry the sample before a reasonably correct sieve analysis can be made. The process up to the hot bins is inaccessible and hostile. The high heat, dust, rotating machinery and elevated location make any inspection dangerous, even if the facility could be modified to provide for sampling.

The only location at which sampling is provided for is at the drop below the hot bins, and even this is an awkward and difficult location at many plants. This is the one point in the process for which considerable data are available. Material can be sampled from the truck into which the pug mill discharges, but testing of such samples for the aggregate gradation is complicated by the fact that the bitumin must first be extracted.

It became clear then that the output of the plant could be conveniently thought of as the drop from the hot bins. In accepting this one makes the assumption that the proportion of the output from the various hot bins is accurately blended in accordance with the prescribed hot mix formula. As typically this blending is done by weight with calibrated and automatically controlled equipment, the assumption of insignificant error beyond the sampled point is reasonable.

The technique employed in formulating the model was then merely to simulate the output of the plant. This output

was considered to be observed at the drop below the several hot bins. This procedure avoided many pitfalls that would have resulted in attempting to simulate the entire process. Furthermore, the plant simulated would be a typical New York State plant rather than a specific plant. This general simulation results from the fact that the modeling and calibration is done with state-wide data collected from many different plants.

In the typical simulation, time is one of the fundamental variables. The program processes the flow for an increment of time and then the procedure is repeated for the next time increment. The asphalt batch plant by its very nature has incremented time with the series of batches, and the continuous plant can be considered to be a stream of batch-sized flow elements.

In the adopted procedure, time is treated indirectly as an implied variable with the individual batches handled consecutively. While most simulations require several cycles to load the system and reach a steady-state situation, this model is not dependent on any such initializing period.

EVALUATION OF THE PROCESS

Types of Tests

Several testing methods may be employed to evaluate the aggregate gradations produced by the asphalt plant and to assure quality control (18). Three such tests are described to demonstrate the testing procedure.

The tolerance test checks the percent passing each sieve for the combined mix sample representing the entire batch. This percent passing must lie within the range of the values deliniated by the job mix formula, plus or minus an associated tolerance limit. If a batch has a percent passing outside this range for any sieve, the batch is deemed to be out of specification.

The present approach used by New York State is to establish the tolerance limits so that five percent of the material evaluated by each sieve will fall outside the acceptable range. As the area under the normal curve between -2 and +2 standard deviations is 95 percent of the total area, the tolerance limits were set at ± 2 standard deviations.

The uniformity test examines only the percent retained on the primary size sieve for a bin. It is a shortcut test as compared with a complete sieve analysis. The primary-size percent retained must not be less than the specified uniformity test limit. The value currently used by New York State is 70 percent for both Bins 1 and 2. If the primary-size percent retained is less than this limit for either bin, the batch is out of specification.

The uniformity difference test monitors variation in primary size between the batches tested. The test compares the percent retained on the primary-size sieve with the primary size of the previous batch tested. If the absolute value of the difference is greater than the specified uniformity difference limit, the batch is out of specification.

The number of such checks is always one less than the number of batches tested, as the first batch tested cannot be evaluated. New York's uniformity difference limit is presently 12 percent.

Testing Errors

There are several accidental errors that are inherent in testing procedures used to estimate the gradation of the aggregate. The three primary sources of error result from sampling, splitting and sieving operations (6). The combined error from these sources is herein called the "testing error".

The sampling error occurs because a very small sample on the order of a gallon is used to estimate the characteristics of an entire batch. The magnitude of the sampling error may be estimated by comparing samples taken very close together time-wise, so that the bin gradations may be assumed to be in a steady-state condition.

Once a sample is obtained it is commonly put through a splitter to obtain the amount of material which can be conveniently sieved. Some error is introduced as the splitter does not divide the sample into two parts with identical gradations. When four quarters of a split sample which was split twice are sieved, however, the comparison of the results can be used to estimate the splitting error.

A further error is introduced during the sieve analysis, because sample sieving is never completely reproducible even when the same sample is resieved. This error can be determined

by the sieving, recombining and resieving the identical sample.

The testing error represents the difference between the true gradation of a batch and the estimate of that gradation as obtained by sieving a sample taken from the batch.

Testing Strategy

A testing strategy is the sequence in which the various tests are applied and the decision rules that are utilized to evaluate the material produced by the plant. For example, one may elect to sample every tenth batch and to employ three uniformity tests followed by one tolerance test. If, however, a batch fails the uniformity test, a special sample will be taken and a tolerance test applied before deciding to accept or reject the product. Such a strategy involves a specific testing effort. A goal that can be studied by use of the simulation model is the trade-off between effective control of the process and the testing effort applied.

One criteria that may be used to evaluate a testing strategy is the number of batches that are outside of specification. The basic criteria of control is to reduce the variation of the product; therefore, the testing strategy should reject the tails of the production distribution while accepting the bulk of the batches which lie close to the mean.

Due to sampling inadequacies and the testing error, some material may be rejected that is in reality acceptable (Type I Error) and, conversely, other material may be accepted

that should be rejected (Type II Error). It is desirable to keep these so called producer's and buyer's risks within acceptable bounds (<u>10</u>).

DESCRIPTION OF THE MODEL

THE PROGRAM

The basic concept of the simulation is quite simple and easy to comprehend, if one does not get lost in the complex details of programming. In essence, a typical plant is selected and batch by batch the production for, say, one day is generated. The true gradation is recorded (an item never known in the real world), as well as the apparent gradation as obtained from the sieving of a small sample from each batch. The results of various tests are then determined for batches at selected intervals, and the action taken in accepting or rejecting batches is noted. The effect of these sporadic tests of the apparent gradations are then compared with the proper decisions that would have occurred from knowing the true gradation of all batches.

Production

A step-by-step description of the program is presented in the simplified flow chart shown as Figure 5. The first step is to initialize the program and read in the input variables. These variables, listed in Table 2, describe the plant to be simulated, give operating instruction to the program, calibrate the process based on field observations and set forth the specifications and the testing procedure to be followed. The specifications are described in detail in Appendix D.

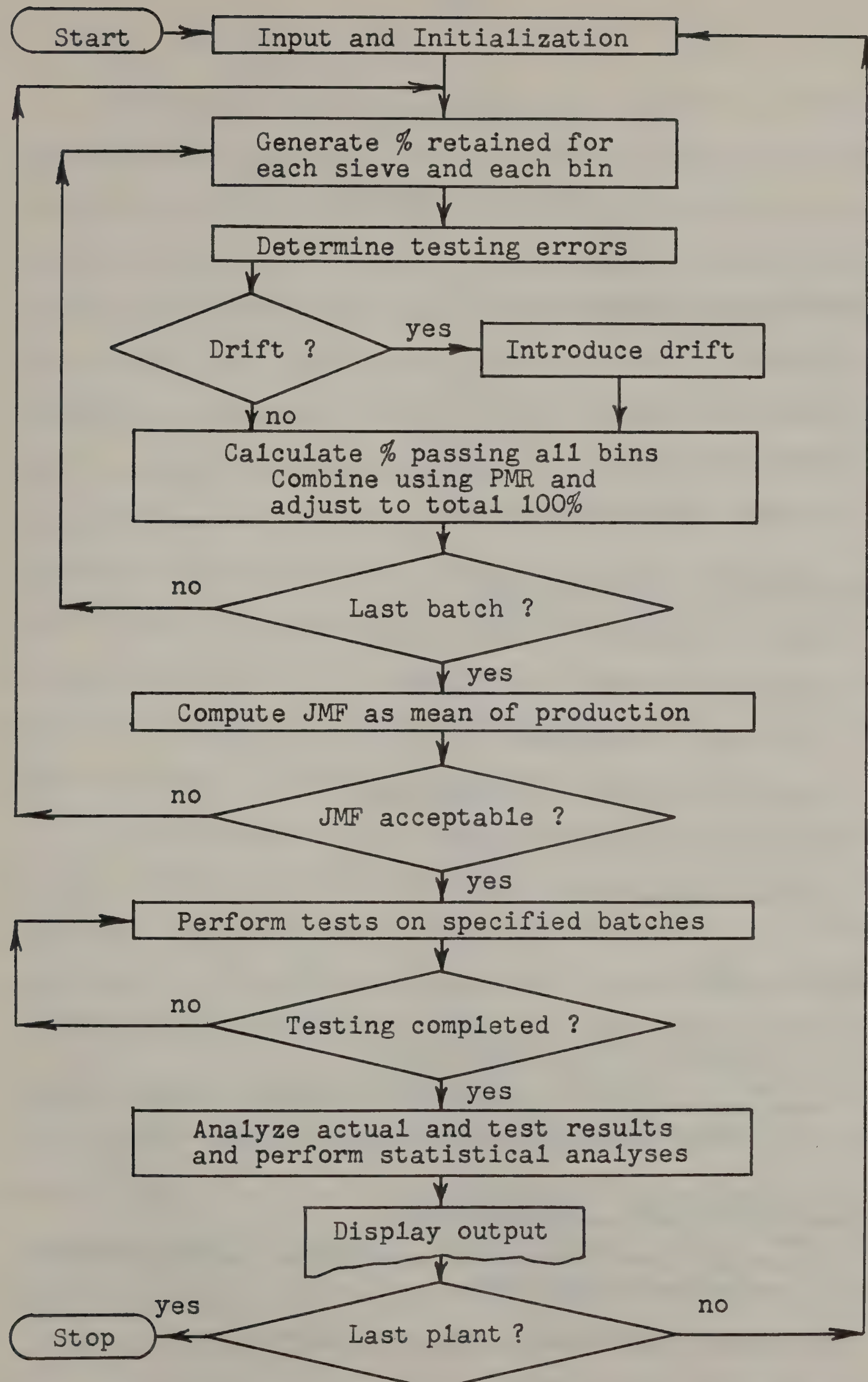


FIGURE 5. BASIC FLOW CHART FOR THE SIMULATION MODEL

T A B L E 2

INPUT INFORMATION

Plant Description Variables

Number of bins

Number of sieves

Plant mix ratio

Primary size for each bin

Program Operating Instructions

Number of plants to be simulated

Number of batches per plant

Frequency of sampling

Amount of output to be displayed

Actuator for drift option

Random number seeds

Calibration Data

Mean and standard deviation of percent retained on each sieve for each bin

Mean and standard deviation of testing errors (adjustments) for each sieve for each bin

Testing Procedure and Specifications

Upper and lower limits of acceptable job mix formula for each sieve size

Tolerance test limits for each sieve size

Uniformity test limit

Uniformity difference test limit

The next step is to generate the percent retained on each sieve for each bin. This is accomplished by generating a random fraction and using it to enter a cumulative frequency plot for each sieve. Figure 6 illustrates this procedure, whereby the random fraction 0.56 is used to obtain a 77 percent retained on the 1/8 inch sieve of Bin 2. The curve is stored as a series of points and linear interpolation is used to obtain the actual value. At the same time the standard deviation of the percent retained and the mean and standard deviation of the testing error are obtained. These three values are stored as a function of the percent retained and are selected by the same random fraction. A more detailed description of the procedure for storing these variables is shown in Figure 8 of Appendix D.

The adjustment to be applied for the testing error is the mean adjustment plus a randomly selected standard deviation for the adjustment. The adjusted percent retained is then the true percent retained plus the adjustment.

The percent retained for all sieves must total 100 percent, because none of the sample is lost. However, as the percent retained values are selected randomly for each sieve, there is no built-in balance to force them to total the necessary 100 percent. Hence, these numbers are standardized in effect by multiplying each value by the ratio of 100 to the sum of the individual values. It is possible under this mathematical procedure for one of the factored values to become negative -- a physical impossibility. If

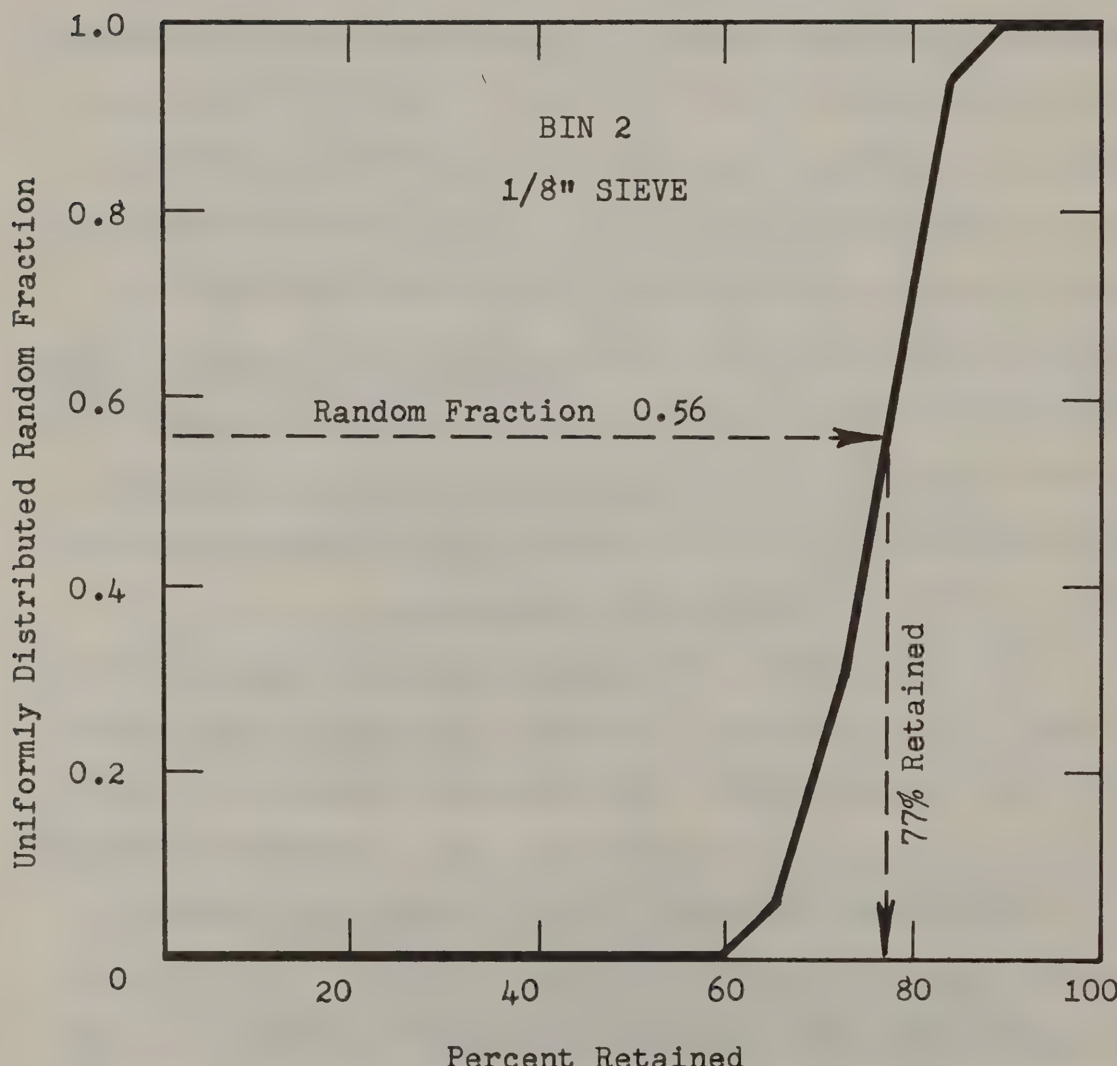


FIGURE 6. THE RANDOM SELECTION
OF THE PERCENT RETAINED ON A SIEVE

this occurs, the value is set to zero and the remaining values are factored to total 100 percent. The question then arises as to whether the resulting standardized values have distributions that are similar to the original observations. Appendix B demonstrates that such an assumption is reasonable.

The percent retained on each sieve is then combined for all bins and the percent passing is computed for the combined sample. The plant mix ratio gives the proportion of the final mix taken from each bin. Table 3 illustrates this calculation.

The above procedure is then repeated for each batch until the specified amount of production is completed. The job mix formula is computed as the mean of the percent passing for each sieve for the entire production. This is a reasonable assumption as the job mix formula is typically based on the past gradation records of the plant. Field observations have shown that the job mix formula is a close approximation of the average gradation when a plant is operating properly (5).

The individual values of the percent passing each sieve as calculated for the job mix formula are checked against the State's band of acceptable values. If any sieve value is found to lie outside the band, the job mix formula is not acceptable and would not be approved. Therefore, the plant is not realistic and the simulation is terminated. As the band is quite large, this circumstance would rarely occur. An adjustment of the plant mix ratio corrects the problem, if

TABLE 3

EXAMPLE OF THE CALCULATION OF THE PERCENT PASSING

Sieve Size	Percent Retained Bin 1	Bin 2	Bin 3	Calculated Percent Passing
1/2	0.0	0.0	0.0	100.0
1/4	80.0	6.0	0.0	78.2
1/8	18.2	82.0	10.6	44.3
#20	1.1	10.1	35.1	25.2
#40	0.1	1.7	30.2	11.1
#80	0.3	0.1	10.0	6.5
#200	0.2	0.0	8.1	2.8
Pan	0.1	0.1	6.0	0.0
Plant Mix Ratio	0.25	0.30	0.45	

Example for Percent Passing 1/8 inch sieve:

Total mix % retained 1/2" = 0.0

Total mix % retained 1/4" = (80.0)(0.25)+(6.0)(0.30)+(0.0)(0.45)
= 21.8%

Total mix % retained 1/8" = (18.2)(0.25)+(82.0)(0.30)+(10.6)(0.45)
= 33.9%

% passing 1/8" = 100.0 - 0.0 - 21.8 - 33.9 = 44.3%

it should develop.

Testing and Evaluation

The various tests are then applied to the plant's production. Table 4 lists the output information which is displayed for each plant that is simulated.

Tolerance Test. The standard deviation of the percent passing is calculated for each sieve when the job mix formula is found. It is multiplied by 2 to form the calculated two-sigma tolerance limit. These limits, however, are not used in the actual tolerance check, but rather the imposed tolerance limits which were specified in the input are used for this purpose. The calculated two-sigma limits are displayed along with the imposed tolerances for comparison purposes.

Each batch has its percent passing for each sieve size checked to determine whether it falls within the imposed two-sigma tolerance limits from the job mix formula. If a batch has any percent passing outside the limits, the entire batch is declared outside of specification. The tolerance test is the base on which the two other tests (uniformity and uniformity difference) are evaluated. Whatever the tolerance test labels a batch is assumed to be the true situation.

Uniformity Test. The uniformity test utilizes the final percent retained on the designated primary size sieve for those bins having a specified primary size. Each percent retained is compared to the uniformity limit given in the input. If the value falls below the specified minimum, a reject is indicated.

T A B L E 4

OUTPUT INFORMATION

Input Information

(See Table 2 on page 34)

Job Mix Formula

JMF calculated as the mean for the plant's production

For each sieve size the calculated and imposed tolerance, upper and lower limits are displayed

Tolerance Test

Table showing the batch number and sieve size for each rejection

Histogram of the number of sieves on which a rejection occurred

Histogram of the number of times each sieve rejected batches

Uniformity Test

Table showing the batch number and bin number for each rejection

Histogram of the number of bins in which a rejection occurred

Histogram of the total number of rejects by each bin

Uniformity Difference Test

Batch numbers and bin numbers for each rejection

Histogram of the number of bins in which a rejection occurred

Histogram of the total number of rejects by each bin

Summary of Results for all Three Tests

For each test the number and percent of batches is given for each of the following:

(1) Total acceptances
(2) Total rejections
(3) Acceptances that should have been accepted
(4) Rejections that should have been rejected
(5) Acceptances that should have been rejected
(6) Rejections that should have been accepted

Uniformity Difference Test. The uniformity difference test utilizes the final percent retained on the primary size sieve from batch to batch. Each percent retained is compared with the corresponding value for the previously tested batch. If the absolute value of the difference is greater than the specified input uniformity difference limit, a reject is indicated.

Table of Results. Following the application of the various tests, the testing limits and strategies are evaluated. The number of tolerance, uniformity and uniformity difference test acceptances and rejections are tabulated and the percentages of acceptances and rejections by each test are calculated. At this point the tolerance limit for each sieve can be determined for the plant to yield the desired percentage of out-of-specification batches that is deemed acceptable.

The uniformity and uniformity difference limits can be calibrated not only according to the percent of samples outside of specification, but also so that the Type I and Type II errors are at an acceptable level. At present there are no State guidelines on the acceptable magnitude of Type I and II errors, however, 10 percent risks for both the producer's and buyer's risks seem reasonable.

Random Variable Generation

A series of uniformly distributed random numbers is generated by the multiplicative congruential method in which each succeeding number is a mathematical function of the preceding number.

To illustrate, let N_0 be the initial random number or the seed of the number series. Subsequent numbers are then generated according to the formula

$$N_{i+1} = \rho \cdot N_i \pmod{b^n};$$

where ρ is a suitable multiplier, b is the number base of the computer and n is the number of digits in the word size of the computer. The resulting number is then divided by the largest number that can be generated to give a decimal fraction which is uniformly distributed over the interval between zero and unity.

The series may be reset at any time to repeat itself by setting N_i back to N_0. Likewise, several independent random number series may be maintained by using different seeds.

Random variables are also required that are not uniformly distributed, but follow some other prescribed distribution. This is accomplished by utilizing the fact that any random variable, no matter what its distributional form, has its cumulative distribution function uniformly or rectangularly distributed over the interval (0, 1); [denoted R (0,1)]. Therefore; by using a random fraction from R (0, 1) one can obtain the corresponding value for the argument x of the cumulative distribution function $F(x)$ for the random variable — that is $x = F^{-1}(x)$, the inverse of the cumulative distribution $F(x)$.

This procedure is demonstrated in Figure 7. Here, a uniformly distributed random fraction between 0 and 1 is used to obtain a normally distributed random variate between -3.4 and +3.4, with a mean of zero. The cumulative distribution curve is approximated by a series of straight line segments.

The result in this example may be used as a randomly selected deviation (d) to be applied to a known mean ($\bar{x}$) and known standard deviation (σ). That is, any particular value (x) is computed as

$$x = \bar{x} + \sigma \cdot d .$$

In the case of a normally distributed variable a mathematical solution could be utilized in place of the described method. In many instances, however, the distributional form is only graphically known. For example, Figure 6 illustrated the selection of a percent-retained value which is based on a distribution observed in the field.

This procedure was used in the study primarily for its versatility. That is, for the same random number generation routine, any form of F(x) can be inserted be it empirical, analytical or an approximation to an analytical expression. It was considered that such generality more than offset the loss of efficiency as compared with routines tailor-made for a specific distributional form.

Drift Option

A drift routine is contained in the program and is available as an option called for by the input control cards.

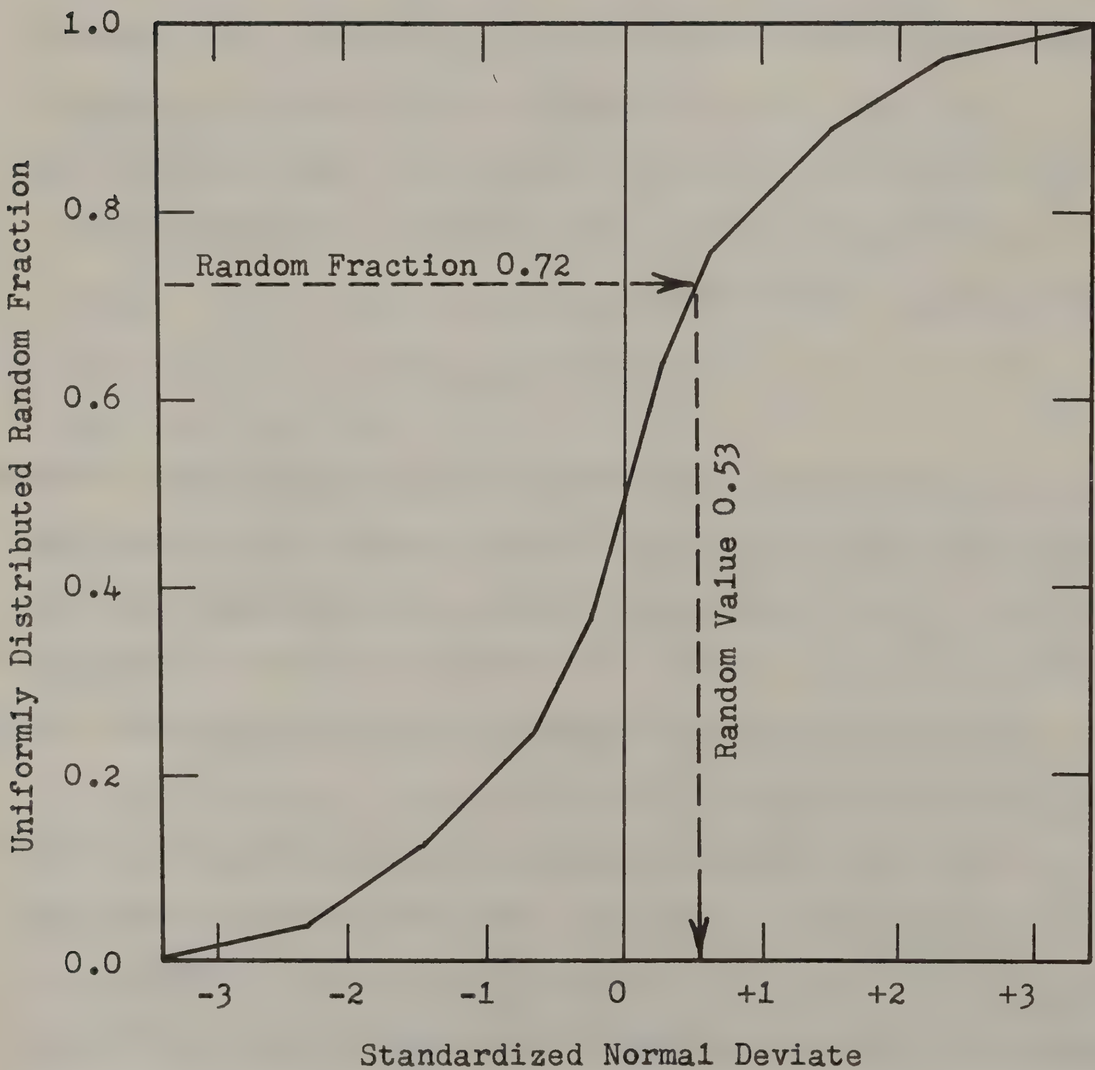


FIGURE 7. THE RANDUM SELECTION

OF A STANDARDIZED NORMAL DEVIATE

The provision of drift adds a realism to the simulation which could not be accommodated as easily in an analytical solution. It enables one to investigate a testing scheme's relative sensitivity in detecting drift in the production process.

Field observations indicated that gradations occasionally tend to drift from the overall mean of plant production. This drift is primarily due to external forces affecting normal plant operations. Gradations drifted back to the mean either when corrective measures were instituted or when external pressures causing the drift subsided.

Fluctuation in the rate of production is a major influence on gradation uniformity. Production surges occur frequently during plant startup when many trucks are waiting to be loaded. As plant production approaches capacity, more aggregate must be separated by the vibrating screens and screen efficiency drops with a resulting carry-over of materials. This carry-over may occur when excessive charging of the screens causes smaller material to be trapped and carried along with the larger stone or when screens become plugged. In either case the aggregate is not allowed to drop into the proper hot bin.

Torn or worn screens also influence production uniformity by permitting oversized particles to drop into the wrong hot bin. Carry-over and faulty screens tend to reduce the percent-retained primary size in the hot bins. This reduction may be considered as a negative drift from the plant mean and is the more prevalent type of drift.

An increase in the percent-retained primary size, termed a positive drift, is also possible. It may occur when plant production slows to well below normal. Numerous other variables such as stockpile gradation and cold feed intermixing may also shift the mix gradation.

The program only applies drift to the percent retained on the primary size sieve for bins which have such a primary size designated. All sieves for the bin are affected, however, when the percent-retained values are adjusted to total 100 percent.

When the drift option is activated, the type of drift (negative or positive), the length of the drift in batches, the intensity of the drift and the frequency of drifting are selected as a random process. The drift applied complies with a parabolic function that reaches its maximum value in two-thirds of its duration and then returns to the mean.

<u>Subroutines</u>

The program was built as a series of building blocks to facilitate change and refinement. Several sub-programs were used for reoccurring portions of the program. These SUBROUTINES are described as follows:

(1) Subroutine NØRMAL accepts a uniformly distributed random number between 0 and 1 and uses it to generate a normally distributed random value between -3.4 and +3.4 with a mean value of zero. A cumulative normal curve is specified as a series of points thru a DATA statement. The value is obtained by linear inter-

polation between these points, thus assuming that the curve is made up of a series of straight line segments. The resulting value is used as a randomly selected standard deviation for normally distributed data. Figure 7, previously presented, illustrated this procedure.

(2) Subroutine GETVAL selects a mean percent retained and its associated standard deviation. These values are obtained by linear interpolation from a family of curves input to the main program for each bin and each sieve.

(3) Subroutine GRAPH plots frequency histograms in a bar chart form. Each graph is automatically scaled to fit on a single page. Up to ten different frequencies can be accommodated. The arguments are the number of different frequencies, the individual values of each frequency, and the title of the graph.

(4) Subroutine ZERØUT sets the entries in any array to zero. It is used to zero the frequencies used in subroutine GRAPH.

(5) Subroutine RANDU generates a uniformly distributed random fraction in the interval 0 to 1.

CODING

The program was coded in the FORTRAN IV compiler language which is extensively used by engineers and scientists.

The use of this coding language facilitates communication and results in a product that may be understood, used and modified by other researchers. To aid in understanding the program,detailed information is given in the Appendices.

Appendix C lists and defines the variables used. The actual program is listed as Appendix F. The frequent use of COMMENT statements in the listing serves to further describe the detailed aspects of the program.

FINDINGS

CONCLUSIONS

Within the state-of-the-art, the Monte Carlo simulation technique offers the most potential for modeling the bituminous concrete plant. Such a simulation can be effectively performed by a digital electronic computer. Insufficient knowledge exists to model the entire process within the plant, however, a model of the plant's output is both feasible and acceptable.

The conceptual model developed is sufficient to demonstrate the usefulness of the program and its applicability to the study of quality assurance procedures. The effectiveness of the program can be further enhanced by additional refinement and field calibration.

The simulation model offers significant advantages over conventional field studies in evaluating various testing strategies and selecting test specifications and limits. Production can be investigated in the laboratory at low cost under highly controlled and reproducible conditions.

RECOMMENDATIONS

The extensive time-series field data collected by the State of New York should be employed to further improve and calibrate the simulation model.

The model should be used to evaluate various testing

procedures and to select an optimum testing strategy and realistic test specifications and limits.

Further development of the model should proceed together with a modest program for the collection and correlation of field data in order that the model be firmly based on reality.

Refinements in the program are needed in handling drift and to accommodate the situation where changes in the plant control variables are made during a production run.

The techniques employed in this research and the program building blocks developed should be applied to the study of quality assurance for other bulk construction materials, such as portland cement concrete.

LIST OF REFERENCES

1. Barber Greene Company, "Dryer Principles," Sales Manual Page 9205, Aurora, Illinois, November 1960.

2. Churchman, C. W., Ackoff, R. L. and Ackoff, E. L., Introduction to Operations Research, John Wiley & Sons, Inc., New York, 1957, Ch. 1 and 7.

3. Draper, N. R. and Smith, H., Jr., Applied Regression Analysis, John Wiley & Sons, New York, 1966, Ch. 8.

4. Goode, H. H., Pollmar, C. H. and Wright, J. B., "The Use of a Digital Computer to Model a Signalized Intersection," Proceedings, Highway Research Board, Vol. 35, (1956), pp. 548-557.

5. Graham, M. D., Burnett, W. C. and Thomas, J. J., "Realistic Job-Mix Formula Tolerances for Asphaltic-Concrete," Record, No. 184 (1967), Highway Research Board, pp. 55-66.

6. Idaho Department of Highways, Materials and Research Division, "Statistical Approach to Quality Control," Research Project No. 11, May 1967.

7. Lewis, R. M. and Michael, H. L., "Simulation of Traffic Flow to Obtain Volume Warrants for Intersection Control," Record, No. 15, Highway Research Board (1963), pp. 1-43.

8. Martin, F. F., Computer Modeling and Simulation, John Wiley & Sons, New York, 1968.

9. Martin, J. R. and Wallace, H. A., Design and Construction of Asphalt Pavements, McGraw-Hill Book Company, New York, 1958, pp. 67-87.

10. Miller-Warden Associates, "Development of Guidelines for Practical and Realistic Construction Specifications," National Cooperative Highway Research Program Report 17, 1965.

11. Newmann, D. L., "Mathematical Method for Blending Aggregates," Journal of the Construction Division, American Society of Civil Engineers, No. CO2 (Sept. 1964), pp. 1-13.

12. New York State Department of Public Works, Division of Construction, "Public Works Specifications," Jan. 2, 1962, p. 256.

13. New York State, Department of Public Works, Bureau of Materials, "Materials Method 5 - Plant Inspection of Bituminous Concrete," April 1967.

14. Shipiro, S. S. and Wilk, M. B., "An Analysis of Variance Test for Normality (Complete Samples)," Biometrika, Vol. 52 (1965), pp. 591-611.

15. Shipiro, S. S. Wilk, M. B. and Chen, H. J., "A Comparison Study of Various Tests for Normality," Journal, American Statistical Association, Vol. 63 (1968), pp. 1343-1372.

16. Stephens, J. E., "Reduction of Apparent Aggregate Variation through Improved Sampling," Joint Highway Research Council, Report No. JHR 66-1, May 1966, pp. 4-6.

17. The Asphalt Institute, Asphalt Plant Manual, Manual Series No. 3, College Park, Md., March 1967, Ch. 3.

18. Ibid. Ch. 4.

19. The Asphalt Institute, The Asphalt Handbook, May 1968.

20. Wohl, M. and Martin, B. V., Traffic System Analysis for Engineers and Planners, McGraw-Hill Book Co., New York, 1967, Ch. 4.

21. Ibid, pp. 499-513.

GLOSSARY

The terms in this list are defined in the specific sense in which they are used in this report:

<u>Final Mix</u>. The mix of aggregate sizes produced at the output end of the plant as the composite of the material dropped from the hot bins.

<u>Job Mix Formula (JMF)</u>. The target gradation expressed as the percent passing each sieve for which the producer aims in the final mix.

<u>Percent Passing</u>. The percentage of aggregate by weight passing a given sieve as computed for the final mix by using the plant mix ratio and the results of the sieve analyses for the individual bins.

<u>Percent Retained</u>. The percentage of aggregate by weight retained on a given sieve as determined by the sieve analysis of a sample for an individual bin.

<u>Plant Mix Ratio (PMR)</u>. The percentage of the aggregate by weight which is dropped from each of the hot bins to make up the final mix.

<u>Testing Error</u>. The difference in the true percent retained for the aggregate in a bin and the observed value which contains the composite errors resulting from the sampling, splitting, and sieving operations.

<u>Tolerance Test</u>. A test in which the percent passing each sieve for the final mix sample is compared with the value delineated by the job mix formula plus and minus a <u>tolerance limit</u> for each sieve.

<u>Uniformity Difference Test</u>. A test which compares the percent retained on the primary-size sieve for a bin against the value observed for the previous batch tested to ascertain whether the absolute value of the difference is less than the <u>uniformity difference limit</u>.

<u>Uniformity Test</u>. A test which compares the percent retained on the primary-size sieve for a bin against a specified minimum value called the <u>uniformity limit</u>.

APPENDIX A

EVALUATION OF DISTRIBUTIONAL FORMS

In describing empirical data it is always helpful to be able to model their distribution with an analytical expression. If such an expression is used, the evaluation of its efficacy is desirable. Many measures that provide such an evaluation are available. None of these are particularly powerful to discriminate among various competing models. However, they do provide an objective procedure for casting doubt on a model. When such doubt does not seem warranted at the risk levels required, the conclusion is made that the proposed models seem to be worthy of consideration and use. Two of the more powerful testing procedures are described below. The first is a classical procedure in common use. The second is a newly developed procedure which, for testing for normality of the raw data or transformations of the raw data, is more powerful than the former more general procedure. It is the latter that has been used for evaluating distributional models in this study.

All tests of distributional models involve measures of discrepancies between what is observed empirically and what would be expected if the postulated model was appropriate. For instance, if the data are subdivided into k intervals and o_i denotes the number of

data observed in the i-th interval, e_i denotes the number of data expected in the i-th interval if the model is correct, then the statistic

$$X^2 = \sum_{i=1}^{k} \frac{(o_i - e_i)^2}{e_i}$$

provides a measure of the goodness of fit of the model to the data. If none of the e_i are too small, then this statistic is approximately distributed as a chi-square with degrees of freedom equal to k minus the number of independent uses made of the data to estimate the e_i's. For testing for a Gaussian or normal model where the two parameters of the distribution are estimated from the data, the number of degrees of freedom is k-3. The decision procedure in this instance is as follows. Compute X^2 and reject the hypothesis that the distributional model is correct if $X^2 > \chi^2_\alpha$; k-3 where the probability of observing a chi-square random variable with k-3 degrees of freedom that exceeds χ^2_α ; k-3 is α ($o < \alpha < 1$). Otherwise accept the hypothesis of the appropriateness of the distributional model on the grounds that the data provide insufficient evidence to support an alternative.

The second test (used in this study) is an analysis of variance test for normality developed by Shapiro and Wilk (14). The test statistic for this test, referred to as the W-statistic, is a function of the

deviations of the ordered observations from a straight line obtained by fitting by the method of least squares the ordered observations to the expectations of these ordered observations (where the expectations are based on the assumption of a normal distributional model). Of course, if it is desired to test for lognormality or normality of the square roots etc., such transformations would only need to be performed before employing the W-statistic. If the n ordered observations are denoted by

$$y_1 \leq y_2 \leq y_3 < \ldots < y_n$$

then, Wilk and Shapiro (14) introduce a statistic

$$W = \frac{\left(\sum_{i=1}^{n} a_i\, y_i\right)^2}{\sum_{i=1}^{n} (y_i - \bar{y})^2}$$

where $\bar{y} = \sum_{i=1}^{n} y_i/n$, and the a_i's are related to the expected values of the ordered observations from the standard normal distribution. These a_i's are tabulated in (14) for n=2 (1) 50 and an approximation procedure for evaluating W is provided for larger n. The exact null distribution for W is also tabulated (14) for n=3 (1) 50.

In (14) and (15) considerable attention is given to examining the power of W as compared with other "goodness of fit" criteria, the X^2 test included, and it is found to be more powerful against many alternative models.

It was for this reason that the W-test was chosen for evaluating the goodness of fit of the proposed distributional models in this study.

The operational procedure for use of the W-statistic is as follows: Compute W and reject the hypothesis of normality if

$$W < W_{1 - \alpha; n}$$

where the probability of observing a value of W in excess of $W_{1 - \alpha; n}$ based on a sample of size is $1 - \alpha$ when the model of a normal distributional form is appropriate.

The W-statistic was computed for the raw data, the natural logarithms and square roots of these data for each of three bins from 20 asphalt plants sampled by the New York State Department of Transportation in 1962-64. A Summary of the decisions available using a 10% level of significance is reported in the following tables. Although the evidence is not overwhelming, the single distributional model (for the primary sizes) that appears to be most suitable is that of the normal distribution.

TABLE 5

ANALYSIS OF DISTRIBUTIONAL FORM

BASED ON BIN 1

Using W Statistic at 10% Level of Significance
Number of Plants = 20
Primary Size = 1/4

Distributional Form	Sieve Size 1/2	1/4	1/8	#20	#80	#200
	No. of Plants Accepted by Each Distributional Form					
Normal	8	17	19	12	2	3
Sq. Root	7	16	17	12	2	4
Log_e	2	17	17	5	1	2
	No. of Plants Accepted by Only One Distributional Form					
Normal	2	1	2	0	0	0
Sq. Root	1	0	0	0	0	1
Log_e	0	0	0	0	1	1
	No. of Plants Accepted by All Three Distributional Forms					
All Three	2	16	17	5	0	1

Note: Sieves 1/2, #80 and #200 had very small percent retained values.

TABLE 6

ANALYSIS OF DISTRIBUTIONAL FORM

BASED ON BIN 2

Using W Statistic at 10% Level of Significance
Number of Plants = 20
Primary Size = 1/8

Distributional Form	Sieve Size					
	1/2	1/4	1/8	#20	#80	#200
No. of Plants Accepted by Each Distributional Form						
Normal	0	11	18	20	6	5
Sq. Root	0	14	15	17	5	6
Log_e	0	15	14	15	3	1
No. of Plants Accepted by Only One Distributional Form						
Normal	0	2	3	3	1	2
Sq. Root	0	0	0	0	0	2
Log_e	0	3	0	0	0	0
No. of Plants Accepted by All Three Distributional Forms						
All Three	0	7	14	15	3	1

TABLE 7

ANALYSIS OF DISTRIBUTIONAL FORM

BASED ON BIN 3

Using W Statistic at 10% Level of Significance
Number of Plants = 20
No Primary Size

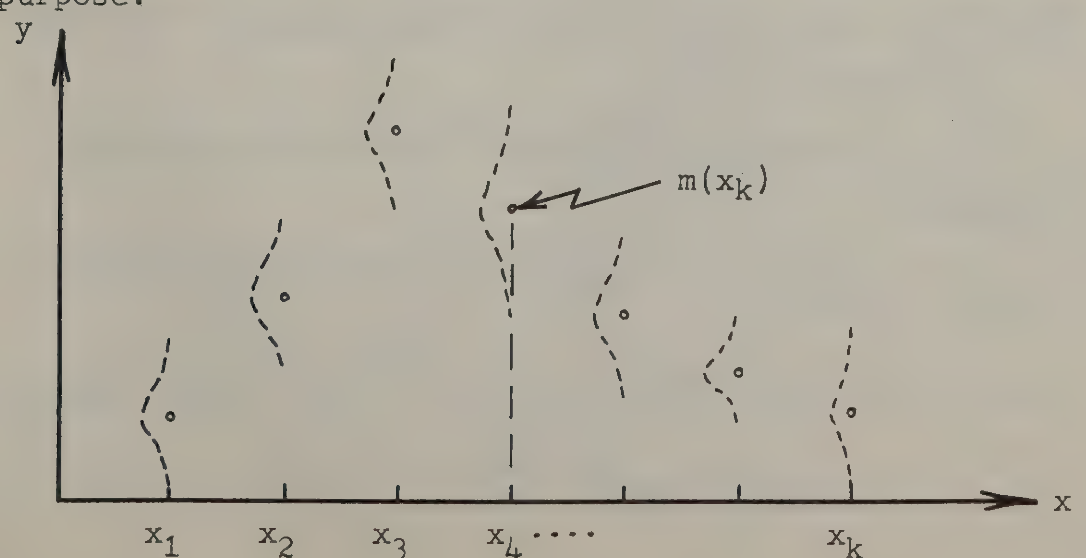
Distributional Form	Sieve Size 1/2	1/4	1/8	#20	#80	#200
No. of Plants Accepted by Each Distributional Form						
Normal	0	1	11	20	20	20
Sq. Root	0	1	13	15	14	14
Log_e	0	0	13	15	14	15
No. of Plants Accepted by Only One Distributional Form						
Normal	0	0	2	4	4	4
Sq. Root	0	0	0	0	0	0
Log_e	0	0	2	0	0	0
No. of Plants Accepted by All Three Distributional Forms						
All Three	0	0	7	14	13	13

Note: Sieves 1/2 and 1/4 had percent retained values close to zero.

APPENDIX B

STANDARDIZATION OF MEASUREMENTS

In the simulation model used, a plant was represented essentially by taking observations from various "percent retained" distributions representing appropriate classes of material. When such numbers are put together, their sum is not likely to add to the desired 100. Hence, for purposes of this investigation, the summing to 100 has been assured by standardizing these numbers by multiplying each observation by the ratio of 100 to the sum of the observations from each class. This standardization raises the question as to whether or not the standardized values have distributions that are similar to the original observations. The rather cumbersome algebra that follows in this appendix leads one to believe that to assume so will not lead one too far wrong. Although based only upon a comparison of moments, which is certainly not a proof, the comparison seemed adequate for the purpose.



Let $y(x_i)$, $i = 1, 2, \ldots, k$ denote a random variable with mean $m(x_i)$ and variance $\sigma^2(x_i)$. That is, we have k distributions that are independent of each other with potentially different means and variances, respectively. Consider the selection of a single observation from each of these k distributions and consider the statistic:

$$y'(x_i) = \frac{y(x_i)}{\sum_{i=1}^{k} y(x_i)} \cdot (100) \qquad (1)$$

Each of the $y(x_i)$'s represent a percent of material retained by sieve of size denoted by the x_i's. Because of sampling errors the sum $\sum_{i=1}^{k} y(x_i)$ may not add up to 100.

By weighting each $y(x_i)$ by $100/\sum_{i=1}^{k} y(x_i)$, the resulting weighted values $y'(x_i)$ will sum to 100. The question then arises: Are the $y'(x_i)$ representing the appropriate distributions? One thing that one would want would be for $E(y'(x_i)) = m(x_i)$. This is approximately the case as is indicated below.

By taking logarithms of both sides of (1) yielding

$$\ln y'(x_i) = \ln 100 + \ln y(x_i) - \ln \sum_{i=1}^{k} y(x_i).$$

$$E[\ln y'(x_i) \cong \ln 100 + \ln m(x_i) - \ln \sum_{i=1}^{k} m(x_i).$$

$$\cong \ln m(x_i),$$

since $\sum_{i=1}^{k} m(x_i) = 100.$

Also, $V[\ln y'(x_i) \simeq V[\ln y(x_i) + V[\ln \sum_{i=1}^{k} y(x_i)]$

$$- 2 \operatorname{cov} [\ln y(x_i), \ln \sum_{i=1}^{k} y(x_i)]$$

$$= \frac{V[y(x_i)]}{m^2(x_i)} + \frac{\Sigma\{V[y(x_i)]\}}{\{\Sigma[m(x_i)]\}^2}$$

$$- \frac{2}{m(x_i)\Sigma\, m(x_i)} \cdot \operatorname{cov}\Big(y(x_i), \Sigma\, y(x_i)\Big)$$

$$= \frac{\sigma^2(x_i)}{m^2(x_i)} + \frac{\sum_{i=1}^{k} \sigma^2(x_i)}{[\Sigma\, m(x_i)]^2} - \frac{2\,\sigma^2(x_i)}{m(x_i)\sum_{i=1}^{k}[m(x_i)]}$$

$$= \frac{\sigma^2(x_i)\{\Sigma' m(x_i)\}^2}{m^2(x_i)[\Sigma m(x_i)]^2} + \frac{\Sigma'\,\sigma^2(x_i)}{[\Sigma m(x_i)]^2}$$

Where Σ' denotes $\sum_{\substack{j=1\\ j\neq i}}^{k}$.

Hence $V[\ln y'(x_i)] \cong \sigma^2(x_i)\left\{\frac{[\Sigma' m(x_i)]^2}{m^2(x_i)[\Sigma m(x_i)]^2} + \frac{\Sigma'\,\sigma^2(x_i)}{\sigma^2(x_i)[\Sigma m(x_i)]^2}\right\}$

$$= \sigma^2(x_i)\left\{\frac{[100-m(x_i)]^2}{m^2(x_i)(100)^2} + \frac{\Sigma'\,\sigma(x_i)}{\sigma^2(x_i)(100)^2}\right\}.$$

$\therefore V[y'(x_i)] \cong \sigma^2(x_i)\left\{\frac{[100-m(x_i)]^2}{100^2} + \frac{m^2(x_i)}{\sigma^2(x_i)} \cdot \frac{\Sigma'\sigma^2(x_i)}{(100)^2}\right\}$

Suppose that $\sigma(x_i)$ is proportional to $m(x_i)$ (which may be a very reasonable supposition). Then:

$$V[y'(x_i)] \cong \sigma^2(x_i)\left\{\frac{[100-m(x_i)]^2}{100^2} + \frac{m^2(x_i)\alpha^2}{\alpha^2 m^2(x_i)}\ \frac{[\sum_{i=1}^{k} m^2(x_i)-m^2(x_i)]}{100^2}\right\}$$

$$= \sigma^2(x_i)\left\{\frac{1}{100^2}\right\}\left\{100^2-2(100)m(x_i)+\sum_{i=1}^{k} m^2(x_i)\right\}$$

$$\geq \sigma^2\ (x_i)\left\{\frac{1}{100^2}\right\}\left\{100^2-2(100)m(x_i) + \frac{[100]^2}{k}\right\}$$

$$= \sigma^2(x_i)\ [\ 1 + \frac{1}{k} - \frac{2m(x_i)}{100}].$$

(The above inequality results from the fact that

$$\sum_{i=1}^{k} m^2(x_i) > \frac{1}{k}\ [\Sigma\ m(x_i)]^2$$

which follows from Schwartz Inequality.)

Hence, the above discussion of the mean and variance for $y'(x_i)$ gives one reassurance that the transformed $y(x_i)$'s transformed to guarantee a sum of 100) have expectations and variances not drastically different from the original $y(x_i)$'s. The above approximate solutions depend upon the following:

$$\ln y(x_i) \cong m(x_i) + [y(x_i)-m(x_i)]\frac{1}{m(x_i)}\ ,$$

i.e. the first two terms of the Taylor series expansion of the natural logarithm about the mean.

$$E[\ln y\ (x_i) \cong m(x_i)$$

$$V[\ln y(x_i)] \cong \frac{1}{m^2(x_i)}\quad V[y(x_i)]$$

$$\text{cov}\ [\ln y(x_i),\ \ln y\ (x_j)] = \frac{1}{m(x_i)m(x_j)}\ \text{cov}\ [y(x_i),y(x_j)] = 0$$

$$\text{cov}\,[y'(x_i),y'(x_j)] \simeq D[y'(x_i)]E[y'(x_j)]\text{cov}[\ln y'(x_i),\ln y'(x_j)]$$

$$= E[y'(x_i)]E[y'(x_j)]\text{cov}[\ln 100 + \ln y(x_i)$$

$$- \ln \sum_{i=1}^{k} {}^2(x_i),\ \ln 100 + \ln y(x_j) - \ln \sum_{i=1}^{k} y(x_j)]$$

$$m(x_i)m(x_j)\left\{ \frac{\sum_{i=1}^{k} \sigma^2(x_i)}{[\Sigma\, m(x_i)]^2} - \frac{\sigma^2(x_i)}{m(x_i)\sum_{i=1}^{k} m(x_i)} \right.$$

$$\left. - \frac{\sigma^2(x_j)}{m(x_i)\sum_{i=1}^{k} m(x_i)} \right\} .$$

For special case where $\sigma(x_i) = \alpha\, m(x_i)$, then

$$\text{cov}\,[y'(x_i),y'(x_j)] \simeq m(x_i)m(x_j) \left\{ \alpha^2 \frac{\Sigma\, m^2(x_i)}{[\Sigma\, m(x_i)]^2} \right.$$

$$\left. - \frac{\alpha^2\, m(x_i)}{\Sigma\, m(x_i)} - \frac{\alpha^2\, m(x_j)}{\Sigma(m(x_i)} \right\}$$

$$= \alpha^2(m(x_i)m(x_j)\left\{ \frac{\Sigma\, m^2(x_i)}{100} - \frac{m(x_i) + m(x_j)}{100} \right\} .$$

$$\gtrsim \alpha^2\, m(x_i)m(x_j) \left\{ \frac{1}{k} - \frac{m(x_i) + m(x_j)}{100} \right\} .$$

From the above, it is difficult to appreciate the magnitude of these covariances. For certain combinations of x_i and x_j, the covariance is going to be close to zero. However, for the x_i values near the primary size, the covariance is going to be negative and not necessarily small.

APPENDIX C

DICTIONARY OF FORTRAN VARIABLES

Program Symbol	Meaning of Symbol
MAIN PROGRAM	
	Arrays
ACCREJ	Counter-accepted by tolerance test and rejected by uniformity or difference test
ALLRET	Distribution of mean and standard deviation of percent retained and adjustments
BACC	Counter-accepted by both tests (uniformity or difference and tolerance)
* BINNAM	Bin names
BREJ	Counter-rejected by both tests (uniformity or difference and tolerance)
DRFMAX	Maximum drift
DUR	Duration of drift
FREQ	Counter - total tolerance rejects
FREQ1	Counter - tolerance rejects by sieve
FREQ2	Counter - total uniformity or difference rejects
FREQ3	Counter - uniformity or difference rejects by bin
IRN	Random number seeds
ISTART	Batch at which drift starts
LØLIM	The State's lower job mix formula band
MSTEPS	Increment between samples (same as STEPS)
NPTS	Number of points in ALLRET
PARRY	Accept reject matrix
PASS	Calculated percent passing
PMR	Plant mix ratio
PRMBIN	Primary size sieve designation

Program Symbol	Meaning of Symbol
	Arrays
REJACC	Counter - rejected by tolerance test and accepted by uniformity or difference test
RETAIN	Calculated percent retained values
RN	Generated random numbers
SNAME	Sieve names
STATE	Imposed tolerance limits
STEPS	See MSTEPS
TEMP	Temporary storage of accept-reject matrix
TESTØL	Counter - no. of sieves rejecting a batch
* TIT1	Title for output
* TIT2	Title for output
* TIT3	Title for output
* TIT4	Title for output
* TIT5	Title for output
TØLACC	Counter - tolerance accepts, rejects and percent rejects
UNACC	Counter - uniformity and difference accepts, rejects and percent rejects
UPLIM	The State's upper job mix formula band
	Single Variables
ADJSIG	Number of standard deviations adjustment varies
ADJUST	Value of adjustment of percent retained
AJMEAN	Mean percent retained adjustment
BATCH	Number of batches to be simulated (same as NBATCH)
BIN	Number of hot bins (same as NBIN)
* BLANK	A blank signifies an accept in accept-reject matrix

Program Symbol	Meaning of Symbol
	Single Variables
DIFF	Difference between retained values
DIFRET	Difference between sum percent retained and 100 percent
* DRFN	Signifies the second drift "2ND"
DRFRN	Seed for random numbers that determine drift
DRIFT	Value of drift applied
FIRST	Starting batch of first drift
HITØL	Calculated upper tolerance limit
I	Subscript - general
IAMØN	Counter - number of drifts
IBIN	Subscript - bins
IC	Temporary value of the primary sieve number
IC1	Counter indicating if plots are required
IC2	Counter indicating if plots are required
IDFT	Counter - drift
IFAIL	Number of tolerance rejects
IFIX	Counter - correction on uniformity difference
IGØ	Counter - drift
II	Subscript - general
IN	Input reader = 5
IPBIN1	First bin with primary sieve
IPBIN2	Last bin with primary sieve
IPLT	Current plant number
IPMRT	Rounded fixed value of the sum of plant mix ratios
IPRINT	Number of batches to be printed
IR	Seed for next generated random number

Program Symbol	Meaning of Symbol
	Single Variables
ISAM	Counter - samples
ISAMP	Subscript - sample
ISIEVE	Counter - sieves
ISTAR1	Temporary drift start value, first drift
ISTAR2	Temporary drift start value, second drift
ITEST	Switch value
ITEST1	Counter - steps
ITESTU	Counter - steps
J	Subscript - general
JMF	Job mix formula
JSIEVE	Sieve number of primary size
K	Subscript - general
L	Subscript - general
LØWTØL	Calculated lower tolerance limit
M	Subscript - general
MARK	Counter indicating if JMF is outside State band
MBIN	Subscript - bins
MINC	Difference between samples
MSIEVE	Counter - sieves
N	Subscript - general
NAME	Name of a particular sieve
NBATCH	See BATCH
NBIN	Subscript - bins (also see BIN)
NDRIF	Switch indicating if drift is desired
NØPLT	Number of plants to be simulated

Program Symbol	Meaning of Symbol
	Single Variables
NØPRIM	Number of bins having a primary sieve
NØRRN	Seed for normal random number generation
NP	Subscript - distribution points
NPT	Number of points in a distribution
NSAMP	Total number of batches simulated
NSIEVE	Number of sieves (same as SAMP)
NSTEP	Switch indicating different sampling interval (same as STEP)
NTSAMP	Total number of samples
NUMAC1	Counter - uniformity accepts
NUMAC2	Counter - uniformity difference accepts
ØUT	Output printer = 3
PASS2	Temporary value of percent passing
PCRET	Mean percent retained value
PCRRN	Seed for random numbers that determine RETAIN values
PMRI	Plant mix ratio values times 100
PMRT	Total of plant mix ratio
PRNT	Number of batches to be printed
* R	Signifies a reject "REJ" in accept-reject matrix
RET	Temporary value of percent retained
RETAJ	Adjustment of retained to total 100 percent
RND	A random number
RNPCR	Percent retained random number
SAMP	See NSAMP
SAMP2	Temporary value of the total number of samples

Program Symbol	Meaning of Symbol
	Single Variables
SDIF	Imposed uniformity difference limit
SIEVE	See NSIEVE
SIGMA	Number of standard deviations percent retain varies
SPRIM	Imposed uniformity limit
STATEH	Imposed upper tolerance limit
STATEL	Imposed lower tolerance limit
STDPAS	Standard deviation of percent passings
STDST	Imposed two sigma tolerance limit
STDT	Two sigma limit of percent passing
STEP	See NSTEP
SUMPAS	Sum of percent passing
SUMPSQ	Sum of squared percent passings
SUMRET	Sum of the percent retained values
TEST1	Number of sieves rejecting - tolerance
TEST2	Number of samples rejected by uniformity difference
TESTDF	Number of bins rejecting - uniformity difference
TESTUN	Number of bins rejecting - uniformity
VALADJ	Mean standard deviation of adjustment
VALSTD	Mean standard deviation of percent retained

SUBRØUTINE NØRMAL

	Arrays
* X	Cumulative normal frequency values
* Y	Number of standard deviations

Program Symbol	Meaning of Symbol
	Single Variables
FX	Random number generated (from main program)
I	Subscript - general
IØ	Number of the output printer
J	Subscript - general
NPT	Number of points in cumulative normal distribution
+ VNØR	Number of standard deviations

SUBROUTINE GETVAL

	Arrays
FN	Equivalent of ALLRET main program
W	Bracketing mean adjustments of percent retains
WW	Bracketing standard deviations of mean adjustments
X	Bracketing random numbers
Y	Bracketing mean percent retains
Z	Bracketing standard deviations of percent retains
	Single Variables
+ AMEAN	Mean percent retained
+ AJMEAN	Mean adjustment of percent retained
FACTOR	Interpolation factor
I	Subscript - general
IØ	Number of output printer
J	Subscript - general
K	Subscript - XN value in FN
KK	Subscript - AMEAN value in FN
KKK	Subscript - SIGMA value in FN

Program Symbol		Meaning of Symbol
		Single Variables
	K4	Subscript - AJMEAN value in FN
	K5	Subscript - SIGAJ value in FN
-	M	Sieve number
-	N	Bin number
-	NPT	Number of points in distribution
+	SIGAJ	Standard deviation adjustment
+	SIGMA	Standard deviation percent retained
-	XN	Random number

SUBRØUTINE GRAPH

		Arrays
-	FREQ	Number of rejects
	JFREQ	Frequency storage
*	LINE	Dashes for output
	NSW	Counter for plotting
-	TITLE	Title of plot
		Single Variables
*	ASK	An "*"
*	BLANK	A "blank"
	FMAX	Maximum frequency
	I	Subscript - general
	ISAL	Scaling factor for plot
	IX	Scale of print out
	J	Subscript - general
	K	Subscript - general
	MAX	Maximum scaled value

Program Symbol		Meaning of Symbol
		Single Variables
-	N	Number of sieves or bins
	NUM	Number printing spaces available
	ØUT	Number of the output printer
	SCAL	Scaling factor for plots
	X	Temporary value

SUBRØUTINE RANDU

		Single Variables
-	IX	Seed for random number
+	IY	Seed for next random number
+	YFL	Generated random number

SUBRØUTINE ZERØUT

		Arrays
-	FREQ	Frequency of rejects
		Single Variables
-	N	Number of sieves or bins

---

* These variables are specified in a data statement

\+ Values sent back to the main program from subroutine

\- Values sent to the subroutine from the main program

APPENDIX D

INPUT CARD SPECIFICATIONS

Card Column No. Numbers	Description of Variables	Variable Name	Field Specification
Card Number One			
1	Number of Plants	NØPLT	I1
Card Number Two			
1-5	Percent retained random no. seed	IRN(1)	I5
6-10	Normal random number seed	IRN(2)	I5
11-15	Drift random number seed	IRN(3)	I5
Card Number Three			
1-5	Tolerance 1/2" sieve	STATE(1)	F5.0
6-10	" 1/4" sieve	STATE(2)	F5.0
11-15	" 1/8" sieve	STATE(3)	F5.0
16-20	" #20 sieve	STATE(4)	F5.0
21-25	" #80 sieve	STATE(5)	F5.0
26-30	" #200 sieve	STATE(6)	F5.0
Card Number Four			
1-5	Upper JMF limit 1/2"	UPLIM(1)	F5.0
6-10	" " " 1/4"	UPLIM(2)	F5.0
11-15	" " " 1/8"	UPLIM(3)	F5.0
16-20	" " " #20	UPLIM(4)	F5.0
21-25	" " " #80	UPLIM(5)	F5.0
26-30	" " " #200	UPLIM(6)	F5.0
Card Number Five			
1-5	Lower JMF limit 1/2"	LØLIM(1)	F5.0
6-10	" " " 1/4"	LØLIM(2)	F5.0
11-15	" " " 1/8"	LØLIM(3)	F5.0
16-20	" " " #20	LØLIM(4)	F5.0
21-25	" " " #80	LØLIM(5)	F5.0
26-30	" " " #200	LØLIM(6)	F5.0

Card Column No. Numbers	Description of Variables	Variable Name	Field Specification
Card Number Six			
1-5	Uniformity limit	SPRIM	F5.0
6-10	Uniformity difference limit	SDIF	F5.0
Card Number Seven			
1-5	Number of batches	BATCH	F5.0
6-10	Number of bins	BIN	F5.0
11-15	Number of sieves	SIEVE	F5.0
16-20	Drift actuator	DRIFT	F5.0
21-25	Number of steps	STEP	F5.0
26-30	Number of batches printed	PRNT	F5.0
Card Number Seven A (Optional-insert card only if STEP=0 on Card Seven)			
1-5	Value of Step	STEPS(1)	F5.0
6-75	Up to 14 more step values	...STEPS(15)	14F5.0
Card Number Eight			
1-5	PMR Bin #1	PMR(1)	F5.0
6-10	PMR Bin #2	PMR(2)	F5.0
11-15	PMR Bin #3	PMR(3)	F5.0
Card Number Nine			
1-5	Primary Sieve Bin #1	PRMBIN(1)	F5.0
6-10	" " Bin #2	PRMBIN(2)	F5.0
11-15	" " Bin #3	PRMBIN(3)	F5.0

Card Number Ten and Eleven, etc.

A pair of input cards are used to describe each sieve of each bin. For example, a three bin, six sieve plant requires 18 different two-card sets.

The first card of each set defines the bin number and sieve number. The second card describes the distributions of the mean percent retained, the standard deviation of the percent retained, the mean adjustment, and the standard deviation of the adjustment for up to three points on the distribution. A distribution may be described by up to 40 points (39 assumed straight line segments by additional cards placed behind the second card.

Figure D-1 shows the distribution curve for the percent retained versus the cumulative frequency for the 1/4" sieve of Bin #1. The curve in this example is approximated by two line segments and is defined by three points. The following page shows the procedure for placing this data on a two-card set.

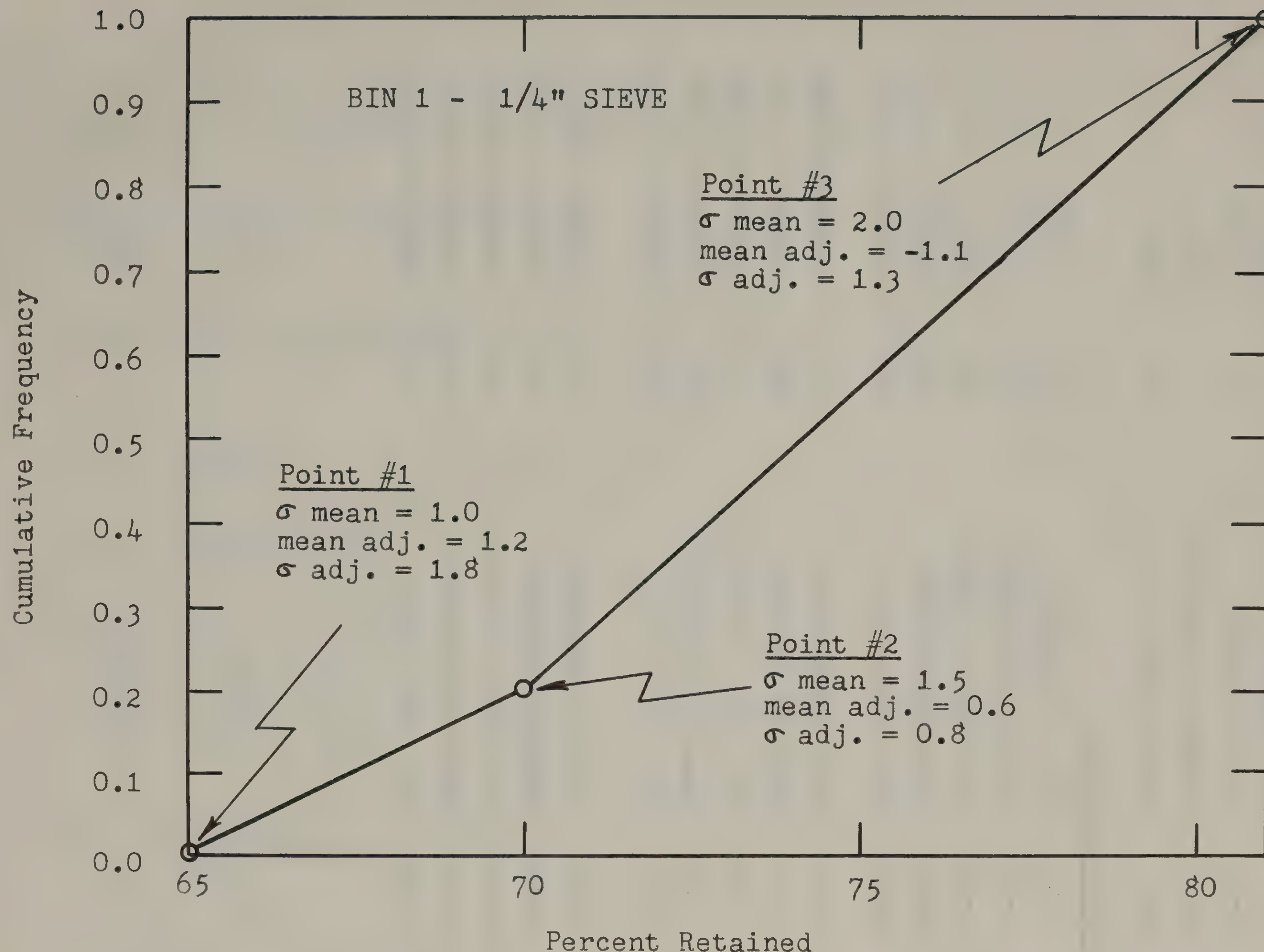


FIGURE 8 EXAMPLE OF INPUT FOR PERCENT RETAINED DATA

Card No.	Column Numbers	Description of Variable	Example Value	Variable Name	Field Specification
First Card of Set					
	1	Bin number	1	IBIN	I1
	2-3	Sieve number	2	ISIEVE	I2
	4-5	Number of points	3	NPT	I2
	6-9	Sieve name	1/4"	NAME	A4
Second Card of Set					
	1-5	Cum. frequency	0.	ALLRET(1,2,1)	F5.0
	6-10	Mean % retained	65.	ALLRET(1,2,2)	F5.0
	11-15	Std. dev. % ret.	1.0	ALLRET(1,2,3)	F5.0
	16-20	Mean adjustment	1.2	ALLRET(1,2,4)	F5.0
	21-25	Std. dev. adj.	1.8	ALLRET(1,2,5)	F5.0
	26-30	Cum. frequency	0.2	ALLRET(1,2,6)	F5.0
	31-35	Mean % retained	70.	ALLRET(1,2,7)	F5.0
	36-40	Std. dev. % ret.	1.5	ALLRET(1,2,8)	F5.0
	41-45	Mean adjustment	0.6	ALLRET(1,2,9)	F5.0
	46-50	Std. dev. adj.	0.8	ALLRET(1,2,10)	F5.0
	51-55	Cum. frequency	1.0	ALLRET(1,2,11)	F5.0
	56-60	Mean % retained	81.	ALLRET(1,2,12)	F5.0
	61-65	Std. dev. % ret.	2.0	ALLRET(1,2,13)	F5.0
	66-70	Mean adjustment	-1.1	ALLRET(1,2,14)	F5.0
	71-75	Std. dev. adj.	1.3	ALLRET(1,2,15)	F5.0

APPENDIX E

EXAMPLE OF PROGRAM OUTPUT

```
                A S P H A L T   P L A N T   S I M U L A T I O N

PLANT NO. 1

      RANDOM NUMBER SEEDS USED FOR THIS PLANT TO INITIALIZE RANDOM NUMBER GENERATORS ARE-
      NCRRN=        333, PCRRN=        987, DRFRN=      78788


      NO. OF      NO. OF      NO. OF      NO. OF
      BATCHES      BINS       SIEVES       STEPS
        200          3           6            0

      SAMPLES ARE OBTAINED FROM EVERY BATCH.


      PLANT MIX RATIOS
      BIN      PERCENT

       1         28.0
       2         32.0
       3         40.0

                                          IMPOSED
      SIEVE    STATE JMF LIMITS          TOLERANCE
        1/2       95. - 100.                 5.0
        1/4       65. -  85.                 5.0
        1/8       32. -  65.                 6.0
         20       15. -  39.                 7.0
         80        3. -  12.                 3.0
        200        0. -   6.                 2.0

      THE UNIFORMITY LIMIT IS 70.00PERCENT AND THE UNIFORMITY DIFFERENCE IS 14.[illegible]
      THE PRIMARY SIZE SIEVES BY BIN ARE-
                SIEVE
         BIN 1   1/4
         BIN 2   1/8

      NO PRICE SPECIFIED FOR THIS PLANT.
```

A S P H A L T   P L A N T   S I M U L A T I O N   C O N T I N U E D

PLANT NO. 1

CALCULATED JOB MIX FORMULA AND IMPOSED JMF TOLERANCES

SIEVE	CALCULATED JMF	CALCULATED TOLERANCE	CALCULATED LOWER LIMIT	CALCULATED UPPER LIMIT	IMPOSED TOLERANCE	IMPOSED LOWER LIMIT	IMPOSED UPPER LIMIT
1/2	100.00	0.0	100.00	100.00	5.00	90.00	100.00
1/4	76.01	4.23	71.78	80.24	5.00	66.01	86.01
1/8	42.58	3.09	39.50	45.67	6.00	30.58	54.58
20	21.91	4.88	17.03	26.79	7.00	7.91	35.91
80	3.46	2.01	1.45	5.47	3.00	0.0	9.46
200	0.00	0.00	0.00	0.00	2.00	0.0	4.00

PLANT NO. 1

PRINT RESULTS ON DETERMINING IF FINAL PERCENT PASSING OF A SAMPLE FOR EACH SIEVE FALLS WITHIN TOLERANCE LIMITS FOR THE SIEVE.
IF=REJ, A REJECT HAS BEEN OBSERVED.

SAMPLE NO.	1/2 SIEVE	1/4 SIEVE	1/8 SIEVE	20 SIEVE	80 SIEVE	200 SIEVE
1						
154		REJ				
200						

A S P H A L T   P L A N T   S I M U L A T I O N   C O N T I N U E D

FREQUENCY PLOT TITLE - NO. OF SIEVES A SAMPLE IS REJECTED ON

FREQUENCY	1	0	0	0	0	0
1	***					
INTERVAL CLASS	1	2	3	4	5	6

FREQUENCY PLOT TITLE - NO. OF TIMES EACH SIEVE REJECTED SAMPLES

FREQUENCY	0	1	0	0	0	0
1		***				
INTERVAL CLASS	1	2	3	4	5	6

A S P H A L T   P L A N T   S I M U L A T I O N   C O N T I N U E D

PLANT NC. 1

ALL 2CC BATCHES EXAMINEC.

TEST ON UNIFCRMITY OF SAMPLES WITH PRIMARY SIZE PERCENT PASSING=70.000

SAMPLE NC.	BIN 1	BIN 2
1		
27	REJ	
28	REJ	
30	REJ	
47	REJ	
58	REJ	
76		REJ
96	REJ	
97		REJ
103	REJ	
120	REJ	
143	REJ	
148	REJ	
154	REJ	
182		REJ
200		

```
FREQUENCY PLCT TITLE - NC. CF BINS A SAMPLE IS REJECTED-UNIFORMITY

FREQUENCY    14        0
--------------------------
     14     ***
     13     * *
     12     * *
     11     * *
     1C     * *
      9     * *
      8     * *
      7     * *
      6     * *
      5     * *
      4     * *
      3     * *
      2     * *
      1     * *
--------------------------
INTERVAL      1        2
CLASS


FREQUENCY PLCT TITLE - TCTAL NC. OF REJECTS BY EACH BIN

FREQUENCY    11        3
--------------------------
     11     ***
     1C     * *
      9     * *
      8     * *
      7     * *
      6     * *
      5     * *
      4     * *
      3     * *      ***
      2     * *      * *
      1     * *      * *
--------------------------
INTERVAL      1        2
CLASS
```

A S P H A L T   P L A N T   S I M U L A T I O N   C O N T I N U E D

PLANT NC. 1

ALL 2CC BATCHES EXAMINED.

TEST CN DIFFERENCE BETWEEN SAMPLES
DIFFERENCE MUST BE EQUAL CR LESS THAN 14.000.

SAMPLE NOS.	BIN 1	BIN 2
1- 2		
4- 5		REJ
26- 27	REJ	
28- 29	REJ	
29- 30	REJ	
30- 31		REJ
47- 48	REJ	
48- 49	REJ	
58- 59	REJ	
64- 65	REJ	
76- 77		REJ
87- 88	REJ	
96- 97	REJ	REJ
97- 98		REJ
103- 104	REJ	
110- 111	REJ	
128- 129	REJ	
142- 143	REJ	
153- 154	REJ	
154- 155	REJ	
167- 168	REJ	
199- 200		

```
FREQUENCY PLOT TITLE - NO. OF BINS A SAMPLE IS REJECTED-UNIFORMITY DIFFERENCE

FREQUENCY    19          1
-------------------------
   19        ***
   18        * *
   17        * *
   16        * *
   15        * *
   14        * *
   13        * *
   12        * *
   11        * *
   10        * *
    9        * *
    8        * *
    7        * *
    6        * *
    5        * *
    4        * *
    3        * *
    2        * *
    1        * *        ***
-------------------------
INTERVAL      1          2
CLASS
```

```
FREQUENCY PLOT TITLE - TOTAL NO. OF REJECTS BY EACH BIN

FREQUENCY    16          5
-------------------------
   16        ***
   15        * *
   14        * *
   13        * *
   12        * *
   11        * *
   10        * *
    9        * *
    8        * *
    7        * *
    6        * *
    5        * *        ***
    4        * *        * *
    3        * *        * *
    2        * *        * *
    1        * *        * *
-------------------------
INTERVAL      1          2
CLASS
```

A S P H A L T   P L A N T   S I M U L A T I O N   C O N T I N U E D

PLANT NO. 1

ALL 200 BATCHES EXAMINED.

T A B L E   O F   R E S U L T S

TEST	NO. OF ACCEPTS	NO. OF REJECTS	PERCENT REJECTED	NO. OF EVENTS ACC-ACC	PERCENT ACC-ACC	NO. OF EVENTS REJ-REJ	PERCENT REJ-REJ	NO. OF EVENTS ACC-REJ	PERCENT ACC-REJ	NO. OF EVENTS REJ-ACC	PERCENT REJ-ACC
TOLERANCE	199.	1.	0.50								
UNIFORMITY	186.	14.	7.00	186.	93.00	1.	0.50	13.	6.50	0.	0.0
UNIFORMITY DIFFERENCE	179.	20.	10.05	179.	89.95	1.	0.50	19.	9.55	0.	0.0

ASPHALT PLANT SIMULATION EXITED NORMALLY

APPENDIX F

LISTING OF FORTRAN PROGRAM

```
C
C
C
C     ASPHALT PLANT SIMULATION
C
C
C
C     MAXIMUM NUMBER OF BATCHES NOW AVAILABLE IS 500.
C
C
C
C     ******************************************************************
C
C     DEFINITION OF ARRAYS AND VECTORS
C
C     ALLRET  -ARRAY BY BIN BY SIEVE BY TOTAL NO. OF POINTS-A DISCRETE
C              DISTRIBUTION CONTAINING AS POINTS THE PERCENT RETAINED
C              MEANS AND STANDARD DEVIATIONS FOR EACH BIN AND EACH SIEVE
C              AND THE MEANS AND STANDARD DEVIATIONS FRO THE ADJUSTMENT
C              DUE TO ERRORS IN SAMPLING, SPLITTING, TESTING, ETC., TO
C              BE MADE TO THE PERCENT RETAINED.
C
C
C     PCRET   -ARRAY BY BIN BY SIEVE--MEAN OF THE PERCENT RETAINED
C              FOR THAT BIN FOR THAT SIEVE FOR THAT PLANT
C
C     VALSTD  -ARRAY OF STANDARD DEVIATIONS CORRESPONING TO PCRET
C
C     ADJMEAN -ARRAY BY BIN BY SIEVE--MEAN OF THE TESTING ERROR
C              DUE TO  SAMPLING,SPLITTING,TESTING,ETC.
C
C     VALADJ  -ARRAY OF STANDARD DEVIATIONS CORRESPONDING TO ADJMEAN
C
C     NPTS    -ARRAY BY BIN BY SIEVE-NO. OF POINTS OF THE ALLRET OR
C              ADJRET DISTRIBUTIONS.
C
C     SNAME   -VECTOR BY SIEVE-THE SIEVE NAMES IN A4 FORMAT.
C
C     PMR     -VECTOR BY BIN-THE PLANT MIX RATIOS IN INCREASING BIN
C              SEQUENCE.
C
C     PRMBIN  -VECTOR BY BIN-THE VALUE IS EQUAL TO THE PRIMARY SIZE
C              SIZE SIEVE FOR THE BIN WAS SPECIFIED.
C
C     RETAIN  -ARRAY BY BATCH BY BIN BY SIEVE-THE PERCENT RETAINED FOR
C              THAT BATCH FOR THAT BIN FOR THAT SIEVE.
C
C     PASS    -ARRAY BY BATCH BY SIEVE-THE PERCENT PASSING FOR THAT
C              BATCH BY SIEVE.
C
C     STATE   -VECTOR BY SIEVE-THE STATE'S IMPOSED TOLERANCE.
C
C     UPLIM   -VECTOR BY SIEVE-THE STATE'S IMPOSED UPPER LIMIT.
C
C     LOLIM   -VECTOR BY SIEVE-THE STATE'S IMPOSED LOWER LIMITS.
C
C     MSTEPS  -VECTOR BY NO. OF SAMPLING PROCEDURES DESIRED-EACH MSTEP
C              CONTAINS THE INCREMENT ON WHICH TO SAMPLE.
```

```
C
C      TESTCL  -VECTOR BY NO. OF BATCHES-IF THE VALUE IS ZERO, THE BATCH
C               WAS ACCEPTED ON TOLERANCE TEST PROCEDURES.  IF THE VALUE
C               IS OTHER THAN ZERO, IT IS EQUAL TO THE NO. OF SIEVES A
C               BATCH WAS REJECTED ON.
C
C
C      ****************************************************************
C
       DOUBLE PRECISION BINNAM
       REAL JMF,LOWTOL,LOLIM
C
       INTEGER OUT,PCRRN,SNAME(10),TEST1,TEST2,TEFTUN,TESTOF,TESTOL,
      1DRFRN,DUR(2)
C
       DIMENSION ALLRET(200),IRN(4),NPTS(5,10),ISTART(2),
      1RN(2),BINNAM(5),RETAIN(500,5,10),PMR(5),
      2PASS(500,10),PRMRIN(5),TESTOL(500),TEMP(2),PARRY(500,10),
      3TOLACC(3),UNACC(2,3),BACC(2,2),ACCREJ(2,2),REJACC(2,2),BREJ(2,2),
      4STEPS(15),FREQ(10),FREQ1(10),FREQ2(10),FREQ3(10),STATF(10),
      5TIT1(20),TIT2(20),TIT3(20),TIT4(20),TIT5(20),UPLIM(10),LOLIM(10),
      6MSTEPS(15),DREMAX(2),DREN(2),PCRET(5,10),VALSTD(5,10),AJMEAN(5,1
      70),VALADJ(5,10),JMF(10),STATFL(10),STATEH(10)
C
       COMMON OUT,ALLRET
C
       EQUIVALENCE (IRN(1),NCRRN),(IRN(2),PCRRN),(IRN(3),DRFRN)
C
       DATA BINNAM/'BIN 1','BIN 2','BIN 3',' IN 4','BIN 5'/,
      1BLANK,R,DREN/'    ','REJ','1ST','2ND'/
       DATA TIT1/'NO. ','OF S','IEVE','S A ','SAMP','LE I','S RE','JECT',
      1'ED O','N   ',10*'  '/,TIT2/'NO. ','OF T','IMES',' EAC','H SI',
      2'EVE ','REJE','CTED',' SAM','PLES',10*'  '/,TIT3/'NO. ','OF B',
      3'INS ','A SA','MPLE',' IS ','REJE','CTED','-UNI','FORM','ITY ',
      49*'  '/,TIT4/'TOTA','L NO','. OF',' REJ','ECTS',' BY ','EACH',
      5' BIN',12*'  '/,TIT5/'NO. ','OF B','INS ','A SA','MPLE',' IS '
      6'REJE','CTED','-UNI','FORM','ITY ','DIFF','EREN','CE  ',6*'  ',
C
C      FORMATS FOR I/O LISTS FOLLOW
C
1      FORMAT(4I5)
2      FORMAT(5F5.0)
3      FORMAT(I1,2I2,A4)
4      FORMAT (14F5.0)
5      FORMAT(I2)
6      FORMAT(I1)
100    FORMAT(///10X,'PLANT MIX RATIO FOR BIN NO.',I2,' IS ZERO OR NEGATI
      1VE.'/)
101    FORMAT(10X,'SIMULATION OF PLANT NO.',I2,' WILL TERMINATE DUE TO ER
      1ROR IN INPUT.')
102    FORMAT(///10X,'THE SUM OF THE PLANT MIX RATIOS IS NOT EQUAL TO 100
      1 PERCENT.'/)
103    FORMAT(///20X,'PLANT MIX RATIOS'/20X,'BIN',5X,'PERCENT'/)
104    FORMAT(19X,I3,7X,F5.1)
105    FORMAT(//26X,'PERCENT PASSING',38X,'PERCENT RETAINED'//37X,
      1'PERCENT'/10X,'BATCH',I4,7X,'SIEVE',6X,'PASSING',17X,'SIEVE',
      25(9X,A5))
106    FORMAT(27X,A4,5X,F7.2,19X,A4,5(7X,F7.2))
109    FORMAT(1H1//42X,'A S P H A L T   P L A N T   S I M U L A T I O N'///
      110X,'NUMBER OF PLANTS TO BE SIMULATED IS',I2,'.')
110    FORMAT(///20X,4('NO. OF',5X)/20X,'BATCHES',5X,'BINS',6X,'SIEVES',
      16X,'STEPS'/21X,I4,7X,3(I3,8X)//)
201    FORMAT(10X,A4,9X,F7.2,6(8X,F7.2))
202    FORMAT(//39X,'CALCULATED JOB MIX FORMULA AND IMPOSED JMF TOLERANCE
      1S  '//23X,4('CALCULATED',5X),1X,3('IMPOSED',8X)/10X,'SIEVE',11X,'
      2JMF',4X,2(5X,'TOLERANCE',4X,'LOWER LIMIT',4X,'UPPER LIMIT')/)
```

```
203   FORMAT(//2X,'PRINT RESULTS ON DETERMINING IF FINAL PERCENT PASSING
     1 OF A SAMPLE FOR EACH SIEVE FALLS WITHIN TOLERANCE LIMITS FOR THE
     2SIEVE.'/10X,'IF=REJ, A REJECT HAS BEEN OBSERVED.'//5X,'SAMPLE'/7X,
     3'NO. ',10(2X,A4,' SIEVE'))
204   FORMAT(5X,I5,5X,10(A3,9X))
205   FORMAT(//10X,'TEST ON UNIFORMITY OF SAMPLES WITH PRIMARY SIZE PERC
     1ENT PASSING=',F6.3//10X,'SAMPLE NO. ',5(2X,A5))
206   FORMAT(10X,I5,9X,5(A3,4X))
207   FORMAT(//10X,'TEST ON DIFFERENCE BETWEEN SAMPLES'/10X,'DIFFERENCE
     1MUST BE EQUAL OR LESS THAN ',F6.3,'.'//10X,'SAMPLE NOS.',5(2X,
     2A5))
208   FORMAT(9X,I4,'-',I4,6X,5(A3,4X))
209   FORMAT(//10X,'NO PRIMARY SIZE SPECIFIED FOR ANY BIN.'//10X,
     1'UNIFORMITY AND TOLERANCE DIFFERENCE ARE NOT ATTEMPTED.'/)
210   FORMAT(/20X,'RANDOM NUMBER SEEDS USED FOR THIS PLANT TO INITIALIZE
     1 RANDOM NUMBER GENERATORS ARE-'/20X,'NORRN=',I10,', PCRRN=',I10,
     2', PRFRN=',I10)
239   FORMAT(1H1,10X,'JMF FOR THE',A4,'SIEVE IS OUTSIDE STATE LIMITS')
243   FORMAT(10X,'THE SIMULATION OF PLANT NO.',I2,' IS TERMINATED BECAUS
     1E THE JMF IS OUTSIDE THE STATE LIMITS.'//)
  300 FORMAT (//////47X,'T A B L E   O F   R E S U L T S'/)
301   FORMAT(13X,52(' *'))
302   FORMAT(14X,'*',11X,3('*',7X),2X,9('*',7X))
303   FORMAT(1H+,53X,4('NO. OF',10X))
304   FORMAT(1H+,26X,'ACCEPTS REJECTS  REJECTED',2(' ACC-ACC'),2(' REJ-R
     1EJ'),2(' ACC-REJ'),2(' REJ-ACC'))
305   FORMAT(1H+,15X,'TOLERANCE')
306   FORMAT(1H+,14X,'UNIFORMITY')
307   FORMAT(1H+,14X,'DIFFERENCE')
308   FORMAT(1H+,28X,F5.0,3X,F5.0,2X,F7.2,1X,4(2X,F5.0,2X,F7.2))
309   FORMAT(1H+,18X,'TEST',5X,2('NO. OF',2X),'PERCENT  EVENTS  PERCENT'
     1,3(' EVENTS  PERCENT'))
400   FORMAT(1H1,10X,'THE FREQUENCY PLOT ENTITLED ',20A4/10X,'WAS NOT
     1 PLOTTED FOR ALL FREQUENCY CLASSES WERE ZERO.'/)
401   FORMAT(20X,'SAMPLES ARE OBTAINED FROM EVERY BATCH.'/)
402   FORMAT(20X,'INTERVALS AT WHICH A SAMPLE IS OBTAINED-'/
     115(27X,I3/'+',20X,'EVERY     TH BATCH.'/))
403   FORMAT(//51X,'IMPOSED'/20X,'SIEVE',4X,'STATE JMF LIMITS',4X,
     1'TOLERANCE'/10(21X,A4,5X,F5.0,' -',F5.0,8X,F6.1/))
404   FORMAT (20X,'THE UNIFORMITY LIMIT IS',F6.2,'PERCENT AND THE UNIFOR
     1MITY DIFFERENCE IS',F6.2,'PERCENT')
405   FORMAT(23X,A5,2X,A4)
406   FORMAT(/20X,'NO DRIFT SPECIFIED FOR THIS PLANT.')
407   FORMAT(/20X,'DRIFT SPECIFIED FOR THIS PLANT.')
408   FORMAT(30X,'START OF  DURATION  MAX.DRIFT'/31X,'DRIFT    IN BATCHES
     1 (PERCENT)')
409   FORMAT(20X,A3,' DRIFT     ,I4,6X,I4,7X,F4.1)
410   FORMAT(20X,'DRIFT WILL BE ADDED TO THE PRIMARY SIZE SIEVES ON THE
     1FOLLOWING BINS-'/25X,'BIN 1')
411   FORMAT(25X,A5)
412   FORMAT(20X,'AND THE SAME AMOUNT OF DRIFT WILL BE SUBTRACTED FROM T
     1HE PRIMARY SIZE SIEVE ON BIN 2.')
420   FORMAT (20X,'THE PRIMARY SIZE SIEVES BY BIN ARE-'/29X,'SIEVE')
500   FORMAT(/10X,'SAMPLED EVERY',I4,'TH BATCH.'/)
501   FORMAT(/10X,'ALL',I4,' BATCHES EXAMINED.'/)
502   FORMAT(/10X,'ANALYSIS OF EACH OF THE',I4,' BATCHES FOR THIS PLANT
     1IS AS FOLLOWS-'//)
10000 FORMAT(1H1//////)
10001 FORMAT(45X,'*',40X,'*')
10002 FORMAT(45X,'*ASPHALT PLANT SIMULATION EXITED NORMALLY*')
10003 FORMAT(45X,42('*'))
11000 FORMAT(1H1,30X,'A S P H A L T   P L A N T   S I M U L A T I O N   C O
     1 N T I N U E D'//10X,'PLANT NO.',I2)
C
C
```

```
C      DEFINE I/O UNITS
       IN=5
       OUT=3
C
C
C      NOPLT-NUMBER OF PLANTS TO BE SIMULATED.  IF=0, ONLY 1 PLT. ASSUMED
       READ (IN,5) NOPLT
C
C      DEFINE RANDOM NUMBERS
C      IRN-RANDOM NUMBER SEEDS.(MAX. OF 4 AVAILABLE)
C      READ IN RANDOM NUMBER SEEDS
       READ(IN,1)IRN
C      NCRRN=IRN(1)
C      PCRRN=IRN(2)
C      CRFRN=IRN(3)
       READ(IN,4)STATE
       READ(IN,4)UPLIM
       READ(IN,4)LOLIM
C      READ UNIFORMITY AND UNIFORMITY DIFFERENCE LIMITS
       READ(IN,2)SPRIM,SDIF
       IF (NOPLT)112,112,113
112    NOPLT=1
C      PRINT HEADING
113    WRITE(OUT,109)NOPLT
       DO 11111 IPLT=1,NOPLT
C      PRINT HEADING FOR PLANT
       WRITE(OUT,11000)IPLT
C
C      READ PARAMETERS
C
C      BATCH=TOTAL NO. OF SIMULATED BATCHES REQUESTED
C      BIN=NO. OF HOT BINS
C      SIEVE=NO. OF SIEVES
C      DRIFT-IF 0, NO DRIFT DESIRED, OTHERWISE DRIFT INCLUDED IN
C      DETERMINATION OF PERCENT RETAINED.
C      STEP=NO. OF STEPS, I.E. INCREMENT ON BATCH SO THAT FOR EVERY
C      SIMULATED BATCH AS MODIFIED BY STEP A SIMULATED SAMPLE IS OBTAINED.
C      PRNT=0 IF ANALYSIS ON ALL BATCHES IS TO BE PRINTED.
C
       READ(IN,4)BATCH,BIN,SIEVE,DRIFT,STEP,PRNT
C      INITIALIZE TOTAL NO. BATCHES
       NBATCH=BATCH
       NTSAMP=BATCH

       NBIN=BIN
       NSIEVE=SIEVE
       NDRIF=ABS(DRIFT)
       NSTEP=STEP
       IPRNT=PRNT
       WRITE(OUT,210)NCRRN,PCRRN,CRFRN
       WRITE(OUT,110)NBATCH,NBIN,NSIEVE,NSTEP
       IF(NSTEP)14,14,12
C
C      SET NSTEP=1 IF ZERO OR NEGATIVE
C
12     READ(IN,4)(STEPS(I),I=1,NSTEP)
       DO 6666 I=1,NSTEP
6666   MSTEPS(I)=STEPS(I)
C      READ PLANT MIX RATIOS BY INCREASING BIN NOS.
14     READ(IN,2)(PMR(J),J=1,NBIN)
C      READ WHICH BINS HAVE THE PRIMARY SIZES.  VALUE IS EQUAL TO
C      WHICH SIEVE IN DESCENDING SEQUENCE IT IS.
       READ(IN,2)(PRMBIN(MBIN),MBIN=1,NBIN)
       IPBIN1=0
       IPBIN2=0
```

```
      DO 2222 IBIN=1,NBIN
      IF (PRMBIN(IBIN))2222,2222,24
C     FIND BEGINNING AND ENDING BINS WHICH HAVE PRIMARY
C     SIZE SIEVE REQUIREMENT
24    IF (IPBIN1)34,34,35
34    IPBIN1=IBIN
35    IPBIN2=IBIN
2222  CONTINUE
      IF (NSTEP)93,93,94
93    WRITE(OUT,401)
      GO TO 95
94    WRITE(OUT,402)(NSTEPS(I),I=1,NSTEP)
95    WRITE(OUT,103)
C     CHECK PMR'S
      PMRT=0.0
      DO 22 I=1,NBIN
      PMRI=PMR(I)*100.0
      WRITE(OUT,104)I,PMRI
      IF (PMR(I))13,13,22
13    WRITE(OUT,100)I
      WRITE(OUT,101)IPLT
      GO TO 11111
22    PMRT=PMRT+PMRI
      IPMRT=PMRT+0.5
      IF (IPMRT.EQ.100) GO TO 15
      WRITE(OUT,102)
      WRITE(OUT,101)IPLT
      GO TO 11111
C
C     READ ALLRET DISTRIBUTIONS(ANY ORDER AS LONG AS READ AS A SET).
C
15    DO 33 I=1,NBIN
      DO 33 J=1,NSIEVE
      READ(IN,3)IBIN,ISIEVE,NPT,NAME
C     GET SIEVE SIZE NAME
      SNAME(ISIEVE)=NAME
      NPT=NPT*5
      NPTS(IBIN,ISIEVE)=NPT
      READ (IN,4) (ALLRET(NP),NP=1,NPT)
      CALL RANDU(PCRRN,IR,RNPCR)
      PCRRN=IR
C
C     OBTAIN MEAN AND STANDARD DEVIATION FOR PERCENT RETAINED AND
C     MEAN AND STANDARD DEVIATION FOR ADJUSTMENT FACTOR DUE TO ERRORS
C     IN SAMPLING, SPLITTING, AND TESTING.
C
33    CALL GETVAL (NPT,RNPCR,PCRET(IBIN,ISIEVE),VALSTD(IBIN,ISIEVE),AJME
     1AN(IBIN,ISIEVE),VALADJ(IBIN,ISIEVE))
      WRITE(OUT,403)(SNAME(ISIEVE),LOLIM(ISIEVE),UPLIM(ISIEVE),STATE
     1(ISIEVE),ISIEVE=1,NSIEVE)
      DO 8888 I=1,2
8888  DUR(I)=0
      IF (IPBIN1)116,116,115
115   WRITE (OUT,404)SPRIM,SDIF
      WRITE (OUT,420)
      DO 9999 I=IPBIN1,IPBIN2
      IC=PRMBIN(I)
9999  WRITE(OUT,405)BINNAM(I),SNAME(IC)
C     DRIFT SECTION(SETUP)-ONLY APPLIES FOR 1A TOP WITH 3 HOT BINS.
      ITHRU=0
      IF (NDRIF)116,116,117
116   WRITE(OUT,406)
      NDRIF=0
      ISTAR1=NBATCH+1
      IAMON=0
```

```
      GC TC 123
117   IF (ITHRL)54,123,54
54    NDRIF=1
      CALL RANCU(DRFRN,IR,RND)
      IF (RND-C.75)118,119,119
119   NDRIF=2
118   IAMCN=NDRIF
      ISTAR2=0
      WRITE(CUT,407)
      WRITE(CUT,408)
      DC 7777 IDFT=1,NDRIF
      CALL RANCU(IR,DRFRN,FIRST)
      FIRST=C.5+FIRST*25.C
      ISTART(IDFT)=FIRST+ISTAR2
      CALL RANCU(DRFRN,IR,RND)
      CALL RANCU(IR,DRFRN,DRFMAX(IDFT))
      RND=C.5+RND*5C.C
      DUR(IDFT)=25+RND
      DRFMAX(IDFT)=3.C+4.0*DRFMAX(IDFT)
      ISTAR2=ISTART(IDFT)+DUR(IDFT)
      IR=DRFRN
      WRITE(CUT,409)DRFN(IDFT),ISTART(IDFT),DUR(IDFT),DRFMAX(IDFT)
7777  DRFMAX(IDFT)=9.0*DRFMAX(IDFT)/(2.0*DUR(IDFT))
      ISTAR1=ISTART(1)
      CALL RANCU(DRFRN,IR,RND)
      NDRIF=1
      WRITE(CUT,41C)
      IF (RND-C.5C)121,121,122
122   WRITE(CUT,412)
      NDRIF=-2
      DRFRN=IR
      GC TC 123
121   CALL RANCU(IR,DRFRN,RND)
      IF (RND-C.50)123,123,124
124   NDRIF=NDRIF+1
      IF (RND-0.8C)126,126,125
125   NDRIF=NDRIF+1
126   WRITE(CUT,411)(BINNAM(I),I=2,NDRIF)
123   IDFT=0
      IGC=C
      WRITE(OUT,11000)IPLT
      IF (IPRNT)149,149,150
149   WRITE(CUT,5C2)NBATCH
C
C     THIS SECTICN CBTAINS PERCENT RETAINED FOR EACH SIEVE.
C     INCREMENTS CN SIEVES, BINS, AND SAMPLES.
C
15C   DC 66 ISAMP=1,NBATCH
      IF (ITHRL)136,129,136
C
C     CHECK FOR DRIFT CN OR NOT.
C
136   IF (ISAMP-ISTAR1)129,128,128
128   IF (IAMON-IDFT)127,127,130
13C   IGC=IGC+1
      ISTAR2=ISTAR1-1
      GC TC (131,132,133),IGC
131   IDFT=1
      GC TC 134
132   ISTAR1=ISTART(2)
      IDFT=0
      GC TC 136
133   IDFT=2
134   ISTAR1=ISTAR1+DUR(IDFT)
      GC TC 129
```

```
127   NDRIF=0
      IDFT=0
      ISTAR2=NBATCH+1
129   DO 77 IBIN=1,NBIN
C     PICKUP PRIMARY SIZE SIEVE FOR THIS BIN IF THERE IS ONE.
      JSIEVE=PRMBIN(IBIN)
C
C     SET SUM OF PERCENTAGE RETAINED VALUES TO ZERO.  THIS IS USED LATER
C     TO CORRECT PERCENTAGE RETAINED FOR A BIN TO 100 PERCENT.
C
      SUMRET=0.0
      DO 88 ISIEVE=1,NSIEVE
C
C     PICK UP RANDOM NUMBERS
C
      CALL RANDU(NCBRN,IR,RN(1))
      CALL RANDU(IR,NCBRN,RN(2))
      CALL NORMAL(RN(1),SIGMA)
C     GET SIGMA ADJUSTMENT FACTOR.
      CALL NORMAL(RN(2),ADJSIG)
      RETAIN(ISAMP,IBIN,ISIEVE)=PCRET(IBIN,ISIEVE)+SIGMA*VALSTD(IBIN,ISI
     1EVE)
C
C     GET ADJUSTMENT FACTOR DUE TO ERRORS IN SAMPLING, SPLITTING, AND
C     TESTING.
      ADJUST=ADMEAN(IBIN,ISIEVE)+ADJSIG*VALSTD(IBIN,ISIEVE)
C
C     GET PERCENTAGE RETAINED FOR A SAMPLE.
C
      RETAIN(ISAMP,IBIN,ISIEVE)=RETAIN(ISAMP,IBIN,ISIEVE)+ADJUST
C
C     NOW CHECK TO SEE IF DRIFT IS TO BE APPLIED TO THE PRIMARY SIZE
C     SIEVE OR NOT.
C
      IF (ITERL)55,135,55
55    IF (IDFT)135,135,155
155   IF (JSIEVE-ISIEVE)135,137,135
C     IS DRIFT TO BE APPLIED IF IT IS ON.
137   IF (IBIN-IABS(NDRIF))138,138,135
138   BATCH=ISAMP-ISTAR2
C     IF SO, MAKE DRIFT CORRECTION ON PERCENTAGE RETAINED.
C
      DRIFT=DRFMAX(IDFT)*BATCH*(1.0-(BATCH/DUR(IDFT)))/(0.2)
      IF (NDRIF)139,135,140
139   DRIFT=-DRIFT
140   RETAIN(ISAMP,IBIN,ISIEVE)=RETAIN(ISAMP,IBIN,ISIEVE)+DRIFT
C
C     AFTER ALL THIS, CHECK PERCENTAGE RETAINED FOR ZERO OR NEG.
C
135   IF (RETAIN(ISAMP,IBIN,ISIEVE))16,16,88
16    RETAIN(ISAMP,IBIN,ISIEVE)=0.0
C
C     ACCUMULATE SUM OF PERCENTAGE RETAINED FOR ONE SIEVE SIZE.
C
88    SUMRET=SUMRET+RETAIN(ISAMP,IBIN,ISIEVE)
C
C     END OF SIEVE INCREMENT.  CONTINUE ON BINS.
C
      DIFRET=100.0-SUMRET
      DO 77 MSIEVE=1,NSIEVE
C
C     CORRECT PERCENTAGE RETAINED SO SUM OF PERCENTAGE RETAINED OVER
C     A BIN IS 100 PERCENT.
      RETAJ=(RETAIN(ISAMP,IBIN,MSIEVE)/SUMRET)*DIFRET
      RETAIN(ISAMP,IBIN,MSIEVE)=RETAIN(ISAMP,IBIN,MSIEVE)+RETAJ
77    CONTINUE
```

```
C
C      END OF BIN INCREMENT.  CONTINUE ON FOR BATCHES.
C
C      SET UP FOR FINAL PERCENT PASSING FOR SIEVES.
C
C      SET PERCENT PASSING IN FIRST SIEVE TO 100 PERCENT.
       PASS(ISAMP,1)=100.0
       DO 111 MSIEVE=1,NSIEVE
       PASS2=0.0
       DO 222 MBIN=1,NBIN
C      SUM PERCENT PASSING OVER ALL BINS FOR EACH SIEVE.
222    PASS2=PASS2+PMR(MBIN)*RETAIN(ISAMP,MBIN,MSIEVE)
       PASS(ISAMP,MSIEVE)=PASS(ISAMP,MSIEVE)-PASS2
       IF (MSIEVE-NSIEVE)17,111,111
17     PASS(ISAMP,MSIEVE+1)=PASS(ISAMP,MSIEVE)
111    CONTINUE
       IF (IPRNT)114,114,66
114    WRITE(OUT,105)ISAMP,(BINNAM(I),I=1,NBIN)
       DO 141 MSIEVE=1,NSIEVE
141    WRITE(OUT,106)SNAME(MSIEVE),PASS(ISAMP,MSIEVE),SNAME(MSIEVE)
      1,(RETAIN(ISAMP,MBIN,MSIEVE),MBIN=1,NBIN)
66     CONTINUE
C
C      BEGIN SECTION ON TESTING WHETHER FINAL PERCENT PASSING ON
C      A SIEVE FOR EACH SAMPLE FALLS WITHIN LOWER AND UPPER LIMITS ON THE
C      FINAL PERCENT PASSING ON THE SIEVE.
C
       WRITE(OUT,11000)IPLT
       WRITE(OUT,202)
C
C      PICK UP JMF, STDPASS, AND TOLERANCES ON HIGH AND LOW SIDE OF JMF
C      FOR THE SAMPLE.
C
C      JMF IS OVER ALL SAMPLES FOR EACH SIEVE SIZE BASED ON FINAL PERCENT
C      PASSING FOR EACH SIEVE.
C
       CALL ZEROUT(NSIEVE,FREQ)
       CALL ZEROUT(NSIEVE,FREQ1)
       IC1=1
       MARK=0
       SAMP=NBATCH
       IF (NDRIF)56,57,56
56     IF (ITHRU)240,57,240
57     DO 555 ISIEVE=1,NSIEVE
       SUMPSQ=0.0
       SUMPAS=0.0
       DO 666 ISAMP=1,NBATCH
       SUMPAS=SUMPAS+PASS(ISAMP,ISIEVE)
666    SUMPSQ=SUMPSQ+(PASS(ISAMP,ISIEVE)*PASS(ISAMP,ISIEVE))
       JMF(ISIEVE)=SUMPAS/SAMP
       STDPAS=SUMPSQ-(SUMPAS*SUMPAS/SAMP)
       STDPAS=SQRT(STDPAS/(SAMP-1.0))
       STDT=2.0*STDPAS
       HITOL=JMF(ISIEVE)+STDT
       LOWTOL=JMF(ISIEVE)-STDT
       STDST=2.0*STATE(ISIEVE)
       STATEH(ISIEVE)=JMF(ISIEVE)+STDST
       STATEL(ISIEVE)=JMF(ISIEVE)-STDST
       IF (STATEH(ISIEVE) .GT. 100.) STATEH(ISIEVE)=100.0
       IF (STATEL(ISIEVE) .LT. 0.0) STATEL(ISIEVE)=0.0
       WRITE(OUT,201)SNAME(ISIEVE),JMF(ISIEVE),STDT,LOWTOL,HITOL,STATE
      1(ISIEVE),STATEL(ISIEVE),STATEH(ISIEVE)
       IF (JMF(ISIEVE)-UPLIM(ISIEVE))234,234,236
234    IF(JMF(ISIEVE)-LOLIM(ISIEVE))236,240,240
236    MARK=MARK+1
```

```
240   DO 555 ISAMP=1,NBATCH
      JSIEVE=ISIEVE
C
C     TEST FOR HIGH AND LOW LIMITS ON FINAL PERCENT PASSING
C     FOR EACH SIEVE FOR EACH SAMPLE.
C     TESTOL WILL CONTAIN NO. OF REJECTS OVER SIEVES
C     FOR ALL SAMPLES.
C
      IF (ISIEVE-1)21,21,23
C
C     SET TO TOTAL NO. OF POSSIBLE REJECTS.
C
21    TESTOL(ISAMP)=NSIEVE
23    IF (PASS(ISAMP,ISIEVE)-STATEH(ISIEVE))18,20,19
18    IF (PASS(ISAMP,ISIEVE)-STATEL(ISIEVE))19,20,20
19    PARRY(ISAMP,ISIEVE)=R
C     A REJECT
      FREQ(ISIEVE)=FREQ(ISIEVE)+1.0
      IC1=2
      GO TO 555
20    PARRY(ISAMP,ISIEVE)=BLANK
      TESTOL(ISAMP)=TESTOL(ISAMP)-1
555   CONTINUE
      WRITE(OUT,11000)IPLT
      WRITE(OUT,203)(SNAME(MSIEVE),MSIEVE=1,NSIEVE)
      DO 777 ISAMP=1,NBATCH
      IFAIL=TESTOL(ISAMP)
      IF(IFAIL)777,777,74
74    FREQ1(IFAIL)=FREQ1(IFAIL)+1.0
777   WRITE(OUT,204)ISAMP,(PARRY(ISAMP,ISIEVE),ISIEVE=1,NSIEVE)
C
C     THIS ENDS SECTION DETERMINING IF FINAL PERCENT PASSING FALLS
C     WITHIN ITS LOWER AND UPPPER LIMITS.
C
C     BEGIN SECTION ON TESTING FOR UNIFORMITY AND
C     DIFFERENCE BETWEEN SAMPLES.
C
      GO TO (75,76),IC1
76    CALL GRAPH (NSIEVE,FREQ1,TIT1)
      CALL GRAPH (NSIEVE,FREQ,TIT2)
      GO TO 78
75    WRITE(OUT,400)TIT1
      WRITE(OUT,400)TIT2
78    IF (MARK)241,241,242
242   WRITE(OUT,239)SNAME(JSIEVE)
      WRITE(OUT,243)IPLT
241   IF (IPBIN1)37,37,36
37    WRITE(OUT,209)
      GO TO 11111
36    MINC=1
      NSAMP=NBATCH
      NSTEPS=NSTEPS+1
      NOPRIM=IPBIN2-IPBIN1+1
      DO 5555 ITESTU=1,NSTEP
      WRITE(OUT,11000)IPLT
      ITESTI=ITESTU-1
      IF (ITESTI)60,61,60
60    MINC=MSTEPS(ITESTI)
      WRITE(OUT,500)MINC
      GO TO 142
61    WRITE(OUT,501)NBATCH
142   SAMP=NBATCH/MINC
      WRITE(OUT,205)SPRIM,(BINNAM(I),I=IPBIN1,IPBIN2)
      CALL ZEROUT(NOPRIM,FREQ)
      CALL ZEROUT(NOPRIM,FREQ1)
      CALL ZEROUT(NOPRIM,FREQ2)
```

```
      CALL ZERCUT(NCPBIN,FREQ3)
      IC1=1
      IC2=1
C
C     EXPLANATION OF ARRAYS USED HERE.
C
C     TOLACC(3)    -CONTAINS TOTAL TOLERANCE LIMIT ACCEPTS, REJECTS,
C                   AND PERCENT REJECTED RESPECTIVELY.
C
C     THE FOLLOWING PERTAIN TO BOTH UNIFORMITY AND UNIFORMITY DIFFERENCE
C     WITH THE EXCEPTION THAT RESULTS FOR UNIFORMITY ONLY ARE CONTAINED
C     IN THE FIRST ROW OF THE ARRAYS AND RESULTS PERTAINING TO
C     UNIFORMITY DIFFERENCE ARE CONTAINED IN THE SECOND ROW OF THE
C     ARRAYS.
C
C     UNACC(2,3)   -CONTAINS TOTAL UNIFORMITY ACCEPTS, REJECTS,
C                   PERCENT REJECT IN THE FIRST ROW.
C                   TOTAL UNIFORMITY DIFFERENCE ACCEPTS, REJECTS,
C                   AND PERCENT REJECTED ARE IN ROW 2.
C
C     BACC(2,2)    -RESULTS ON EVENT BOTH ARE ACCEPTED.
C                   COUNTER IN 1ST COLUMN, AND PERCENTAGE IN 2ND COL.
C     ACCREJ(2,2)  -RESULTS ON EVENT ACCEPT FIRST ONE, REJECT ON OTHER.
C                   COUNTER IN 1ST COLUMN, AND PERCENTAGE IN 2ND COL.
C     REJACC(2,2)  -RESULTS ON EVENT REJECT ON FIRST, ACCEPT ON SECOND.
C                   COUNTER IN 1ST COLUMN, AND PERCENTAGE IN 2ND COL.
C     BREJ(2,2)    -RESULTS ON EVENT BOTH ARE REJECTED.
C                   COUNTER IN 1ST COLUMN, AND PERCENTAGE IN 2ND COL.
C
      TOLACC(3)=0.0
C     TURN REJECT COUNTERS AND OTHER COUNTERS TO ZERO.
      DO 4444 I=1,2
      UNACC(I,3)=0.0
      TOLACC(I)=0.0
      DO 4444 J=1,2
      UNACC(I,J)=0.0
      BACC(I,J)=0.0
      ACCREJ(I,J)=0.0
      REJACC(I,J)=0.0
 4444 BREJ(I,J)=0.0
      DO 888 ISAMP=1,NSAMP,MINC
      NUMAC1=0
      NUMAC2=0
      ISAM=ISAMP-1
      DO 999 IBIN=IBBIN1,IBBIN2
      ISIEVE=PRMBIN(IBIN)
      RET=RETAIN(ISAMP,IBIN,ISIEVE)
      IF (RET-SPRIM)25,26,26
 25   TEMP(IBIN)=R
      FREQ(IBIN)=FREQ(IBIN)+1.0
      IC1=2
      GO TO 27
 26   TEMP(IBIN)=BLANK
      NUMAC1=NUMAC1+1
 27   IF (ISAM)28,28,29
 29   DIFF=ABS(RET-RETAIN(ISAM,IBIN,ISIEVE))
      IF (DIFF-SDIF)28,28,31
 28   NUMAC2=NUMAC2+1
      PARRY(ISAMP,IBIN)=BLANK
      GO TO 999
 31   PARRY(ISAMP,IBIN)=R
      FREQ2(IBIN)=FREQ2(IBIN)+1.0
      IC2=2
 999  CONTINUE
```

```
      WRITE(OUT,206)ISAMP,(TEMP(MPIN),MPIN=IPRIN1,IPRIN2)
      TEST1=TESTOL(ISAMP)
      TESTUN=NOPRIM-NUMAC1
      TESTDF=NOPRIM-NUMAC2
      GO TO (80,79),IC1
79    IF (TESTUN) 80,80,179
179   FREQ1(TESTUN)=FREQ1(TESTUN)+1.0
80    GO TO (82,81),IC2
81    IF (TESTDF)82,82,181
181   FREQ3(TESTDF)=FREQ3(TESTDF)+1.0
82    IF (TEST1)38,38,39
39    TOLACC(2)=TOLACC(2)+1.0
C     UPDATE REJECT COUNTER FOR TOLERANCES
38    DO 888 ITEST=1,2
C     MAKE TESTS ON UNIFORMITY AND UNIFORMITY DIFFERENCE FOR THIS SAMPLE
      GO TO (40,41),ITEST
40    TEST2=TESTUN
      GO TO 43
41    IF (ISAM)888,888,42
C     TEST FOR FIRST SAMPLE SINCE UNIFORMITY DIFFERENCE HAS NO MEANING
C     FOR FIRST SAMPLE.
42    TEST2=TESTDF
43    IF (TEST1)45,45,46
C     MAKE VARIOUS TEST AND UPDATE APPROPRIATE COUNTERS
C     A VALUE OF ZERO IS AN INDICATION OF AN ACCEPT.
45    IF (TEST2)47,47,48
46    IF (TEST2)49,49,50
47    BACC(ITEST,1)=BACC(ITEST,1)+1.0
C     EVENT OF BOTH ACCEPTED.
      GO TO 888
C     EVENT OF REJECT ON TEST2 VARIABLE
48    ACCREJ(ITEST,1)=ACCREJ(ITEST,1)+1.0
      GO TO 51
C     UPDATE COUNTER ON UNIFORMITY OR UNIFORMITY DIFFERENCE.
C     EVENT OF REJECT ON TEST1 VARIABLE.
49    REJACC(ITEST,1)=REJACC(ITEST,1)+1.0
      GO TO 888
C     EVENT OF BOTH REJECTED.
50    BREJ(ITEST,1)=BREJ(ITEST,1)+1.0
51    UNACC(ITEST,2)=UNACC(ITEST,2)+1.0
C     UPDATE TEST2 REJECT COUNTER
888   CONTINUE
      IF (ITESTI)85,91,85
91    GO TO (84,83),IC1
83    CALL GRAPH(NOPRIM,FREQ1,TIT3)
      CALL GRAPH(NOPRIM,FREQ,TIT4)
      GO TO 85
84    WRITE(OUT,400)TIT3
      WRITE(OUT,400)TIT4
85    TOLACC(1)=SAMP-TOLACC(2)
      SAMP2=SAMP
      DO 3333 IFIX=1,2
      GO TO (52,53),IFIX
53    SAMP2=SAMP2-1.0
C     DECREASE NO. OF SAMPLES BY 1 SINCE UNIFORMITY DIFFERENCE HAS ONLY
C     N-1 ENTRIES.
52    UNACC(IFIX,1)=SAMP2-UNACC(IFIX,2)
C     GET TABLE VALUES
      TOLACC(1)=SAMP-TOLACC(2)
      TOLACC(3)=100.0*TOLACC(2)/SAMP
70    BREJ(IFIX,2)=100.0*BREJ(IFIX,1)/SAMP2
      REJACC(IFIX,2)=100.0*REJACC(IFIX,1)/SAMP2
71    BACC(IFIX,2)=100.0*BACC(IFIX,1)/SAMP2
      ACCREJ(IFIX,2)=100.0*ACCREJ(IFIX,1)/SAMP2
73    UNACC(IFIX,3)=100.0*UNACC(IFIX,2)/SAMP2
```

```
3333  CONTINUE
      WRITE(OUT,11000)IPLT
      IF (ITESTI)143,143,144
143   WRITE(OUT,501)NBATCH
      GO TO 145
144   WRITE(OUT,500)MINC
145   WRITE(OUT,207)SDIF,(BINNAM(I),I=IPBIN1,IPBIN2)
      DO 1111 ISAMP=2,NSAMP,MINC
      ISAM=ISAMP-1
1111  WRITE(OUT,208)ISAM,ISAMP,(PARRY(ISAMP,IBIN),IBIN=IPBIN1,IPBIN2)
      IF (ITESTI)89,92,89
92    GO TO (87,86),IO2
86    CALL GRAPH(NCPRIM,FREQ3,TIT5)
      CALL GRAPH(NCPRIM,FREQ2,TIT4)
      GO TO 89
87    WRITE(OUT,400)TIT5
      WRITE(OUT,400)TIT4
89    WRITE(OUT,11000)IPLT
      DO 311 I=1,4
      GO TO (312,313,314,315),I
312   IF (ITESTI)146,146,147
146   WRITE(OUT,501)NBATCH
      GO TO 148
147   WRITE(OUT,500)MINC
148   WRITE(OUT,300)
317   WRITE(OUT,301)
      GO TO 311
313   WRITE(OUT,303)
      GO TO 311
314   WRITE(OUT,309)
      GO TO 311
315   WRITE(OUT,304)
      GO TO 317
311   WRITE(OUT,302)
      DO 318 I=1,3
      J=I-1
      WRITE(OUT,302)
      IF (I-1)319,319,320
319   WRITE(OUT,305)
      WRITE(OUT,308)(TOLACC(K),K=1,3)
      GO TO 322
320   WRITE(OUT,302)
      WRITE(OUT,306)
323   WRITE(OUT,308)(UNACC(J,II),II=1,3),(BACC(J,K),K=1,2),(BREJ(J,N),
     1N=1,2),(ACCREJ(J,L),L=1,2),(REJACC(J,M),M=1,2)
      IF (I-2)322,322,321
321   WRITE(OUT,302)
      WRITE(OUT,307)
322   WRITE(OUT,302)
318   WRITE(OUT,301)
5555  CONTINUE
      IF (NDRIF)58,11111,58
58    IF (ITHRU)11111,59,11111
59    ITHRU=1
      GO TO 54
11111 CONTINUE
      WRITE(OUT,10000)
      WRITE(OUT,10003)
      WRITE(OUT,10001)
      WRITE(OUT,10002)
      WRITE(OUT,10001)
      WRITE(OUT,10003)
99999 CALL EXIT
      END
```

```
      SUBROUTINE NORMAL(FX,VNOR)
      DIMENSION X(40),Y(40)
      COMMON IO
      DATA X/0.0,0.0013,0.0062,0.0228,0.0668,0.0587,0.2119,0.3085,0.3821
     1,0.4602,0.5,0.5398,0.6179,0.6915,0.7881,0.8413,0.9332,0.9772,
     20.9938,0.9987,1.0000,19*0.0/,Y/-3.4,-3.0,-2.5,-2.0,-1.5,-1.0,-0.8,
     3-0.5,-0.3,-0.1,0.0,0.1,0.3,0.5,0.8,1.0,1.5,2.0,2.5,3.0,3.4,19*0.0/
     4,NPT/21/
1     FORMAT(//10X,'ERROR-----RANDOM NUMBER WAS OUTISDE THE LIMITS OF TH
     1E NORMAL FUNCTION.'/21X,'VALUE IS SET TO 0.0 .'//)
      DO 22 I=1,NPT
      IF (FX-X(I))11,12,22
12    VNOR=Y(I)
      RETURN
11    J=I+1
      VNOR=Y(I)+(Y(J)-Y(I))/(X(J)-X(I))*(FX-X(I))
      RETURN
22    CONTINUE
      WRITE(IO,1)
      VNOR=0.0
      RETURN
      END


      SUBROUTINE GETVAL (NPT,XN,AMEAN,SIGMA,AJMEAN,SIGAJ)
C     LINEAR INTERPOLATION IS USED TO OBTAIN VALUES.
      DIMENSION X(2),Y(2),Z(2),W(2),WW(2)
      COMMON IO,FN(200)
1     FORMAT(//10X,'ERROR-----VALUES NOT OBTAINED IN SUBROUTINE GETVAL.'
     1/20X,'DATA SPECIFIED WAS OUTSIDE THE FUNCTION LIMITS.'//)
      DO 22 I=1,NPT,5
      IF (XN-FN(I))11,12,22
12    AMEAN=FN(I+1)
      SIGMA=FN(I+2)
      AJMEAN=FN(I+3)
      SIGAJ=FN(I+4)
      RETURN
11    IF (I-1)13,13,15
15    IF (FN(I+1)-FN(I+6))14,12,14
C     POIK UP CORRECT SUBSRCIPT
14    DO 33 J=1,2
      K=I-(5*(2-J))
      KK=K+1
      KKK=K+2
      K4=K+3
      K5=K+4
      X(J)=FN(K)
      Y(J)=FN(KK)
      Z(J)=FN(KKK)
      W(J)=FN(K4)
33    WW(J)=FN(K5)
      FACTOR=(XN-X(1))/(X(2)-X(1))
C
C     NOW MAKE INTERPOLATION
C
      AMEAN=Y(1)+(Y(2)-Y(1))*FACTOR
      SIGMA=Z(1)+(Z(2)-Z(1))*FACTOR
      AJMEAN=W(2)
      SIGAJ=WW(2)
      RETURN
22    CONTINUE
13    WRITE(IO,1)
      RETURN
      END
```

```
      SUBROUTINE GRAPH(N,FREQ,TITLE)
C
C     SUBROUTINE TO PLOT BAR GRAPHS
C     MAX. OF TEN BARS AVAILABLE
C
      INTEGER OUT,BLANK,ASK
      DIMENSION FREQ(N),TITLE(20),JFREQ(10,3),LINE(88),NSW(10)
      DATA BLANK,ASK,LINE/' ','*',88*'-'/
1     FORMAT(1H1,10X,'FREQUENCY PLOT ENTITLED ',20A4/10X,'CANNOT BE PLOT
     1TED AS NO. OF FREQUENCY INTERVALS REQUESTED EXCEEDS LIMIT OF PROGR
     2AM.')
2     FORMAT(1H1,11X,'FREQUENCY PLOT TITLE - ',20A4/)
3     FORMAT(10X,88A1)
4     FORMAT(12X,I4,2X,10(5X,3A1))
5     FORMAT(11X,'EACH ',A1,' EQUALS ',I2,' POINTS.')
6     FORMAT(11X,'CLASS')
7     FORMAT(11X,'INTERVAL',10(5X,I2,1X))
8     FORMAT(11X,'FREQUENCY ',10(I5,3X))
      OUT=3
      IF (N-10)12,12,11
11    WRITE(OUT,1)TITLE
      GO TO 99999
C     SEARCH FOR MAX.
12    FMAX=0.0
      DO 22 I=1,N
      NSW(I)=0
      JFREQ(I,1)=FREQ(I)
      IF (FREQ(I)-FMAX)22,22,13
13    FMAX=FREQ(I)
22    CONTINUE
      WRITE(OUT,2)TITLE
C     SET UP FOR SCALING IF NECSSARY
      ISCAL=1
      IF (FMAX-50.0)14,14,15
15    ISCAL=(FMAX+49.0)/50.0
      WRITE(OUT,5)ASK,ISCAL
14    NUM=8+8*N
      WRITE(OUT,8)(JFREQ(I,1),I=1,N)
      WRITE(OUT,3)(LINE(I),I=1,NUM)
C     CLEAR ARRAY
      DO 77 J=1,N
      DO 77 I=1,3
77    JFREQ(J,I)=BLANK
      SCAL=ISCAL
      MAX=FMAX/SCAL
      DO 44 I=1,MAX
      X=MAX-(I-1)
      DO 55 J=1,N
      IF (FREQ(J)/SCAL-X)55,16,16
16    DO 66 K=1,3
66    JFREQ(J,K)=ASK
      IF (NSW(J))17,18,17
17    JFREQ(J,2)=BLANK
18    NSW(J)=J
55    CONTINUE
      IX=X*SCAL
44    WRITE(OUT,4)IX,((JFREQ(J,K),K=1,3),J=1,N)
      DO 88 J=1,N
88    JFREQ(J,1)=J
      WRITE(OUT,3)(LINE(J),J=1,NUM)
      WRITE(OUT,7)(JFREQ(J,1),J=1,N)
      WRITE(OUT,6)
99999 RETURN
      END
```

```
      SUBROUTINE ZEROUT(N,FREQ)
      DIMENSION FREQ(N)
C     ZERO OUT THE FREQUENCIES
      DO 22 I=1,N
22    FREQ(I)=0.0
      RETURN
      END
```

```
      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*65539
      IF (IY)5,6,6
5     IY=IY+2147483647+1
6     YFL=IY
      YFL=YFL*.4656613E-9
      RETURN
      END
```

01610
LRI